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GROUND ENGINEERS

AERO-ENGINES

INSPECTION OF
DURING MANUFACTURE, OVERHAUL, AND TEST

("C" & "D" LICENCES)

BY
A. N. BARRETT, A.M.I.A.E., A.F.R.Ae.S.

The Air Ministry, whilst accepting no responsibility for the contents of this book, recognizes it as a textbook that should prove to be of value to intending applicants for Ground Engineers' licences

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ELEMENTS AND THEIR SYMBOLS

Element	Symbol	Atomic Weight	Atomic Number	Element	Symbol	Atomic Weight	Atomic Number
Aluminium . .	Al	27·0	13	Molybdenum . .	Mo	96·0	42
Antimony . .	Sb	120·2	51	Neodymium . .	Nd	144·3	60
Argon	A	39·9	18	Neon	Ne	20·2	10
Arsenic . . .	As	74·96	33	Nickel	Ni	58·68	28
Barium . . .	Ba	137·37	56	Niton	Nt	222·4	86
Bismuth . . .	Bi	209·0	83	Nitrogen . . .	N	14·008	7
Boron	B	10·9	5	Osmium . .	Os	190·9	76
Bromine . . .	Br	79·92	35	Oxygen . . .	O	16·0	8
Cadmium . . .	Cd	112·40	48	Palladium . . .	Pd	106·7	46
Calcium . . .	Ca	40·07	20	Phosphorus . .	P	31·04	15
Carbon	C	12·005	6	Platinum . . .	Pt	195·2	78
Cerium	Ce	140·25	58	Potassium . . .	K	39·10	19
Cæsium . . .	Cs	132·81	55	Praseodymium .	Pr	140·9	59
Chlorine . . .	Cl	35·46	17	Radium . . .	Ra	226·0	88
Chromium . . .	Cr	52·0	24	Rhodium . . .	Rh	102·9	45
Cobalt	Co	58·97	27	Rubidium . .	Rb	85·45	37
Columbium . .	Cb	93·1	41	Ruthenium . .	Ru	101·7	44
Copper	Cu	63·57	29	Samarium . . .	Sa	150·4	62
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Holmium . .	Ho	163·5	67	Thallium . .	Tl	204·0	81
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Lead	Pb	207·2	82	Xenon . . .	Xe	130·2	54
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Litecium . . .	Lu	175·0	71	Yttrium . . .	Yt	89·33	39
Magnesium . .	Mg	24·32	12	Zinc	Zn	65·37	30
Manganese . .	Mn	54·93	25	Zirconium . . .	Zr	90·6	40
Mercury . . .	Hg	200·6	80				

[The atomic weight of an element is the weight of an atom of that element as compared with an atom of Hydrogen, which is the lightest known element.]

[The atomic number expresses the position of the element in the periodic table.]

ABBREVIATIONS

Ft.	=	Foot	km.	=	kilometre
Lb.	=	Pound (Av.)	S.G.	=	Specific Gravity
dr.	=	dram	Hg.	=	Mercury
gr.	=	gramme	H_2O	=	Water
kg.	=	Kilogramme	E.M.F.	=	Electro Motive Force
cm.	=	centimetre	π	=	3·1416

INSPECTION OF AERO-ENGINES

Introduction

THE following notes, which deal with the inspection of aero-engines during manufacture, overhaul, and test have been written for those studying with a view to qualifying for the Ground Engineers' "C" or "D" Licences, and the first step is to procure a copy of the Air Navigation Orders, and the latest issue of the Air Navigation Directions. These are both obtainable from H.M. Stationery Office, Adastral House, Kingsway, W.C.2.

Section 3, paragraphs 44 to 54, of the latter document, give particulars relating to the licensing of Ground Engineers and the regulations and conditions governing the issue of a licence.

Paragraph 47 calls attention to the syllabus of the oral examination, referred to in sub-paragraph (*b*) of the previous paragraph in the section. This syllabus is known as Air Ministry Pamphlet No. 34, and should be obtained at the first opportunity. It stresses the importance of studying the Air Navigation Act and the Air Navigation Directions, and with particular reference to Category D the following sections of the Air Navigation Directions are of the utmost importance.

Section 2 (*c*), paragraphs 19 and 20. Here you will find the inspectional requirements that must be exercised throughout the manufacture, and equally the overhaul or rectification of an engine. In effect, it comprises a systematic following through of the inspection of every detail and assembly of an engine from the raw material to the finished product.

Section 2 (*c*), paragraph 21. This refers to the limitations imposed on a Ground Engineer as regards the acceptance of parts which do not conform strictly to the approved drawings.

Section 2 (*h*), paragraphs 34 to 36, refer to the incorporation of modifications affecting the safety of an engine as a condition of airworthiness.

Section 5, paragraphs 58 and 59. These state that the standard of material and workmanship, when overhauling or repairing engines, shall be that required for new engines. It also prescribes the form of certificate that must be inserted in the engine log book, and signed by the ground engineer, on the completion of his supervision Approved log books have the certificate printed at the bottom of each page.

The subject-matter in each of the above sections is referred to in detail elsewhere in the book.

Experience

We must now consider what practical experience might be deemed reasonable before a candidate presents himself for examination. In

the first place he must make up his mind for what approved type or types of engine he intends to qualify. It is quite unlikely that he would be examined, except for named types, unless his experience was exceptional and of long duration, and for this reason it would be necessary for him to obtain practical experience of the erection, dismantling, and testing of each type of engine for which he ultimately required a licence.

The regulations specify that "he shall have had at least two years' satisfactory practical experience, provided, however, that in lieu of such two years' practical experience, proof may be accepted that the candidate has otherwise acquired adequate knowledge of the construction or maintenance of aero-engines," after which proof of his capacity to carry out the duties of a ground engineer in a satisfactory manner would be ascertained by an oral examination. It is thought that the necessary practical experience could best be obtained by employment in an established firm manufacturing aero-engines, or, on the other hand, a properly equipped operating company maintaining their own engines. Most of the time should be occupied in erecting, stripping, and testing engines, preferably those received for overhaul and repair, because it is unlikely that the ground engineer will eventually operate his licence in the manufacture of new engines. The adequacy of the experience so gained would be carefully considered in relation to the number and type of engines applied for, and it will doubtless be necessary to produce testimonials to support this experience. There would be no objection to the candidate applying for one engine only, and adding others to his licence at later dates after the necessary experience had been obtained. If the candidate wished to include any foreign type of engine on his licence, he would be required to produce evidence that he was familiar with, and had overhauled, the particular engine in question, and the statements might, of course, be subject to verification, but even then it is very doubtful whether engines in this class would be considered unless the candidate already held a licence for other engines.

Experience of the kind already referred to would not, of necessity, fit the candidate for satisfactorily fulfilling the requirements of the oral examination, because it is my experience that a person employed in a factory, even though he is erecting and stripping engines, may not have the opportunity of handling certain of the components and accessories, if they are dealt with in other sections of the works, and it should be realized, therefore, that some of the knowledge of an engine that is required may have to be obtained in ways other than from practical experience. In this connection the candidate is strongly recommended to obtain any information, literature, and handbooks that are available on the particular engine in which he is interested. In those instances where the civil type of engine is also a service engine he is advised to obtain the *Service Handbook* from H.M. Stationery Office. These books are very complete and should be exceedingly helpful.

He should also obtain a personal copy of the *Airworthiness Handbook*, A.P. 1208, and amendments from the Air Ministry. This book indicates the detail requirements of a type aircraft which includes,

of course, the engine, in order that it may qualify for a certificate of airworthiness in accordance with Section 2 of the Air Navigation Directions. What is equally important, the book also contains particulars of the bench tests that must be carried out on civil engines after overhaul or rectification, with all of which it is essential for the candidate to be familiar. It also includes a series of Inspection Leaflets of immense value (see Notice to Aircraft Owners and Ground Engineers, No. 39, of 1936), in that they amplify the requirements of the Air Navigation Directions in regard to manufacturing processes. I shall have occasion to refer to some of these Inspection Leaflets in detail later on. Meanwhile, I will say just a few words about Inspection Leaflet No. 100 (A.P. 1208), which includes a chart showing the complete chain of inspection of an aero-engine, and which satisfactorily meets the requirements of the Air Navigation Directions. The leaflet explains at some length the significance of, and the reasons for, the various inspection stages. It will be noted that a record of inspectional responsibility is maintained throughout, either by release note, inspector's stamp on the part, book record, or log sheet signature. The candidate should carefully consider this leaflet, which is applicable equally to new and repair engines, because the oral examination is largely moulded around the various stages.

Approved Material

It should be clear that a ground engineer, holding a licence in category "C," is only permitted to fit approved spares, that is to say, spares supplied by a constructor whose inspection organization has been approved by the Air Ministry. These firms are permitted to manufacture engines and their spares, inspect them by their own Inspection Departments, and subsequently release them, it being necessary, however, to include on their release notes the required certificate and approval reference issued by the Air Ministry. The holder of a "D" licence is considered to have attained sufficient specialized knowledge to enable him to supervise the manufacture and inspection of approved spares, as well as the overhaul and test of the engine into which the spares are subsequently built. It should be clear, then, that the raw material from which approved spares are to be made must also be obtained from, and properly released by, approved firms.

Ferrous materials would be supplied either in the form of bars, billets, forgings, stampings, sheets, or castings. The accompanying release note and test certificates (the latter showing that the relative specification had been met) would enable the material, which would be stamped and batched, to be correlated at the contractor's works. The release note should also indicate whether the material was in the normalized or heat-treated condition. Inspection Leaflet No. 410 (A.P. 1208) deals with the identification of the above material.

The Air Navigation Directions require the candidate to satisfy the Examining Board that he has a sufficiently good knowledge of materials to enable him properly to check incoming raw material and supervise the manufacture of spare parts. Space does not permit me

to deal with the question of materials beyond the standard that may be expected to meet the requirements of the syllabus, but the candidate would be well advised to extend his knowledge by referring to one of the many textbooks on the subject; in particular, it is thought that a knowledge of the iron carbon equilibrium diagram Fig. 3 would be of assistance in more clearly understanding heat-treatment and case-hardening processes.

Specifications

SPECIFICATIONS OF MATERIALS SUITABLE FOR AERO-ENGINE COMPONENTS

Component	Material	Specifications
Crankshaft	High tensile alloy steel	4.S.11, S65, 2.S.81
Reduction gears	Case-hardening steel	S.82, S.90
Smaller gears	High tensile alloy steel	2.S.28, S.90
Connecting rods	High tensile alloy steel	2.S.28, S.65, 4.S.11, 2.L.40
Wrist pins	Case-hardening and high tensile air-hardening steel	S.90, 2.S.28
Gudgeon pins	Case-hardening and high tensile air-hardening steel	S.90, 2.S.28
Cylinder barrels	Carbon steel	2.S.6, S.70, S.79
Water jackets	Carbon steel sheet	S. 84
Camshaft	Case-hardening steel	2.S.14
Airscrew shaft	High tensile alloy steel	4.S.11
Airscrew hub	High tensile alloy steel	4.S.11, S.65
Airscrew hub bolts	High tensile alloy steel	4.S.11, 2.S.2
Inlet valves	Steel stamping	S.62, D.T.D.49B
Exhaust valves	Steel stamping	D.T.D.6A, D.T.D.49B
Valve springs	Steel (hard-drawn)	D.T.D.5A
Valve seatings	Stampings or bar	S.68, D.T.D.160, D.T.D. 192, 247
Oil pump gears	Bar	4.S.11, D.T.D.194
Push rod ball ends	Case-hardening steel bar	2.S.14
Studs (stressed)	High tensile alloy steel bar	2.S.2, S.69
Piston rings	Cast-iron pots	4.K.6, D.T.D.233, 277
Induction fan	Aluminium alloy	D.T.D.133B
Pistons	Aluminium alloy (cast and forged)	4.L.11, 2.L.24 2.L.42 D.T.D.131A
Cylinder heads	Aluminium alloy (cast and forged)	4.L.11.D.T.D.131A, D.T.D.133B 4.L.25
Crankcase	Aluminium alloy (cast and forged)	3 L.5 6.L.1, D.T.D.133B
Covers	Aluminium alloy (cast and forged)	3.L.5., D.T.D.133B
Bearing bushes	Phosphor-bronze bar	2.B.8, D.T.D.155
Bolts and nuts (unstressed)	Mild steel bar	3.S.1
Pressings, clips, and brackets	Mild steel sheet	2.S.3, 2.S.4
Tube for piping	20-ton welding steel	2.T.26
Tube for piping	50-ton Ni-Cr steel	T.50
Tube for push-rod covers	Aluminium	4.T.9
Tube for piping	Seamless copper	5.T.7, 2.T.51
Tube for radiators	Brass	3.T.47

Practically all ferrous and non-ferrous materials used in aero-engine construction conform either to the British Standards Institution Specifications for Aircraft Materials and Components, and are obtainable at 28 Victoria Street, London, or in the case of new grades of material that have not yet reached the stage of development that permits standardization, to those known as D.T.D. Specifications. issued by The Director of Technical Development, Air Ministry, and obtainable at H.M. Stationery Office, Kingsway.

The type engine drawings, from which subsequent engines are manufactured, invariably quote the specifications of the various parts on them, and a list indicating suitable material specifications for the principal parts of an engine is included above for information, it being

clear that the ground engineer must become conversant with the actual specifications corresponding to the particular engine he wishes to hold a licence for, and whilst it is quite unnecessary to memorize these specifications, it is necessary to have a working knowledge of them, and to see that each specification bears the latest prefix and suffix according to the requirements of the constructors' specifications.

It is unlikely, other than in the case of an emergency repair, that the manufacture of new parts will become necessary, but in spite of this it is very desirable for the ground engineer to appreciate the characteristics and merits of the various classes of materials that are available for aero-engine construction. There is, for example, a range of case-hardening steels, namely, 2.S.14, 3.S.15, S.82, etc., comprising a straight carbon, a 3 per cent nickel, and a 5 per cent nickel chrome steel respectively. The first of these, if properly heat-treated and case-hardened, will provide the hardest case, whilst the others, owing to the presence of nickel, have stronger and less fibrous cores, and offer greater resistance to shock loading. Case-hardening nickel steels are, therefore, selected for such parts as gear wheels, but the choice of the material by the manufacturer is largely dependent on the duty the part has to perform, and, to some extent, the design. It is also recognized that the addition of nickel and/or chromium to a steel has the effect of slowing down the critical cooling velocity for hardening and permits the use of quenching media other than water.

This property cannot be made use of in the case of straight carbon case-hardening steels.

One advantage, then, of the alloy steel over the carbon steel is that there is much less risk of surface cracks and distortion of parts where oil quenching can be substituted for the more drastic water quench.

A reference to the specifications will show that high-tensile alloy steels such as 4.S.11, S.65, S.69, S.81, etc., are employed in the heat-treated condition for highly-stressed parts, and as a result do not normally permit of any cold working.

It will sometimes be found that similar parts have been manufactured in more than one class of material, and in such cases it may be assumed that normal development by the engine designers has warranted a change in the material to a later or more suitable specification, as the result of some form of trouble which may have shown up in manufacture or during service operation. It may be found that connecting rods, originally made in material to 4.S.11 specification, have been changed to material to 2.S.28 specification. Cylinder heads originally made in material to 4.L.11 specification may subsequently be produced in material to specification L.43, D.T.D.133B, or D.T.D. 131A; the latter is die cast, and aluminium alloys in this condition are known to have a closer grain and improved physical properties. In such cases the drawing will be the guide as to which is the current specification, and in the event of the parts made to an earlier specification being considered unserviceable for use in an engine, such cases would always be brought to the notice of the ground engineer by the promulgation of a Notice to Aircraft Owners and Ground Engineers.

Another class of material which does not permit of any discretion

on the part of the ground engineer is white-metal for bearings. It is safe to say that most proprietary brands of white-metal fall inside the two existing specifications, namely, 2.B.21 and 2.B.22, and it is important that the brand of white-metal specified by the engine makers, and which was tested on the original type engine, must be used in subsequent engines. It is possible that occasion might arise where it becomes necessary to manufacture bushes for wrist pins, gudgeon pins, and other parts of an engine. In these cases it is important that they are made in the material specified on the type drawings. The use of extruded bronze in place of cast phosphor-bronze, might lead to serious trouble. See Plate I. In the same way the use of aluminium bronze in place of magnesium (specification D.T.D.88B) or steel, for pump gears, or *vice versa*, might be undesirable, as the loading on the teeth and clearance might easily have a bearing on the satisfactory functioning of the parts if a change to an unsuitable material were made.

Exhaust valve steels with high-nickel or chromium content normally fall into the austenitic class, and the rates of expansion on heating are often 50 per cent in excess of normal valve steels. In these cases additional valve guide clearance is essential for satisfactory functioning.

If we briefly consider any one of the high-tensile alloy steel specifications used for the more highly-stressed parts in an aero-engine, we shall find that the specification is divided into sections dealing with the various forms of material that can be obtained, and the requirements as regards the selection and preparation of the mechanical test samples are dealt with in each of the various sections.

It will be found that the chemical analysis of the steel is given, and that certain elements may be included at the option of the purchaser. For example, manganese promotes soundness and freedom from gas cavities, and if not present the steel would be liable to "red shortness." The tensile figure is improved and the ductility unimpaired up to 1 per cent of manganese.

The various mechanical tests required, as well as the form of the test bar, are also included. If the material has been heat-treated before delivery to the constructor, as is often the case, a reference to the relative specification may be required in order to be able to check the sub-contractor's release note to see that the various tests, enumerated in the specification, have been complied with. It will be noted that on small bars, where an Izod test piece cannot be prepared, a nicked fracture test may be substituted. The specification also states that where the mechanical tests after heat-treatment do not meet the specification figures a second heat-treatment is permissible. Where heat-treatments have to be carried out at the constructor's works, the various mechanical test bars must be prepared in accordance with the terms of the specification. If facilities are not available for carrying out these tests they would have to be done at an approved test house.

As regards heat-treatments, the temperatures specified are considered to represent an average figure for general practice only for this particular class of material; the exact temperatures would, of course, be supplied by the steel makers and are normally quoted on the covering release note. The specification points out the necessity of identifying

stampings and other parts at all stages throughout the manufacture, and as identification of the major parts has to be carried through to the finished article this point must not be lost sight of.

Cast Iron. This material is mainly used in aero-engines for piston rings and then contains no more than 3·5 per cent "total" carbon. At elevated temperatures the carbon is taken into solid solution as in the case of steel, but on cooling normally, some carbon is retained in the "combined" form, whilst the rest is precipitated as graphite plates. It is this "free" carbon which makes this class of material excellent as a bearing metal such as would be required for a piston ring moving up and down in a cylinder.

The combined carbon should be not less than ·45 per cent in order that the wearing qualities of the ring are not impaired and to ensure that a fine Pearlitic structure shall be maintained. Combined carbon in excess of ·8 per cent would produce free cementite, which, being very hard, would induce cylinder wear and add to machining difficulties. It is current practice to cast the cylinders or "pots" by a centrifugal process which results in a finer distribution of the graphite and closer grain structure than with the ordinary sand-cast pots, and the risk of inclusions of sand is eliminated. Good quality piston rings can be obtained by casting each ring separately, to dimensions as near as possible to the finished article, but this is probably more costly and the centrifugal method is considered to be an advantage for heat formed rings.

Materials Testing

In order that a specification for material may be fully understood it is necessary for the ground engineer to know the various mechanical tests that are called for, and the reason why they are carried out. It is not essential that he should have actually carried out these tests, and a few details on this particular subject may therefore be helpful.

Tensile Test. This particular test is made in order to determine the ultimate tensile strength, the yield point, the reduction of area, and the elongation of a material. A standard form of test bar is prepared in accordance with the dimensions specified in B.S.I. specification No. 2.A.4. The extremities of the test bar are machined so that they may be accommodated in the jaws of a testing machine. A load is progressively applied to the test bar either by hand, electric, or hydraulic power, according to the type of machine, until it eventually fails in tension.

The test bar is normally machined to ·564 in. diameter on the reduced portion, which corresponds to a cross-sectional area of ·25 sq. in. Two centre pop marks are made on the reduced portion, exactly 2 in. apart. For other sizes of test bar the distance of the gauge points apart is $4\sqrt{\text{area of the test bar}}$, or 3·56 times the diameter of the test bar.

The Yield Point is determined by measuring the extension of these points by means of dividers as the test is in progress, and it will be found that when the yield point is reached there will be a marked extension of the test bar, together with a sudden drop of the beam of

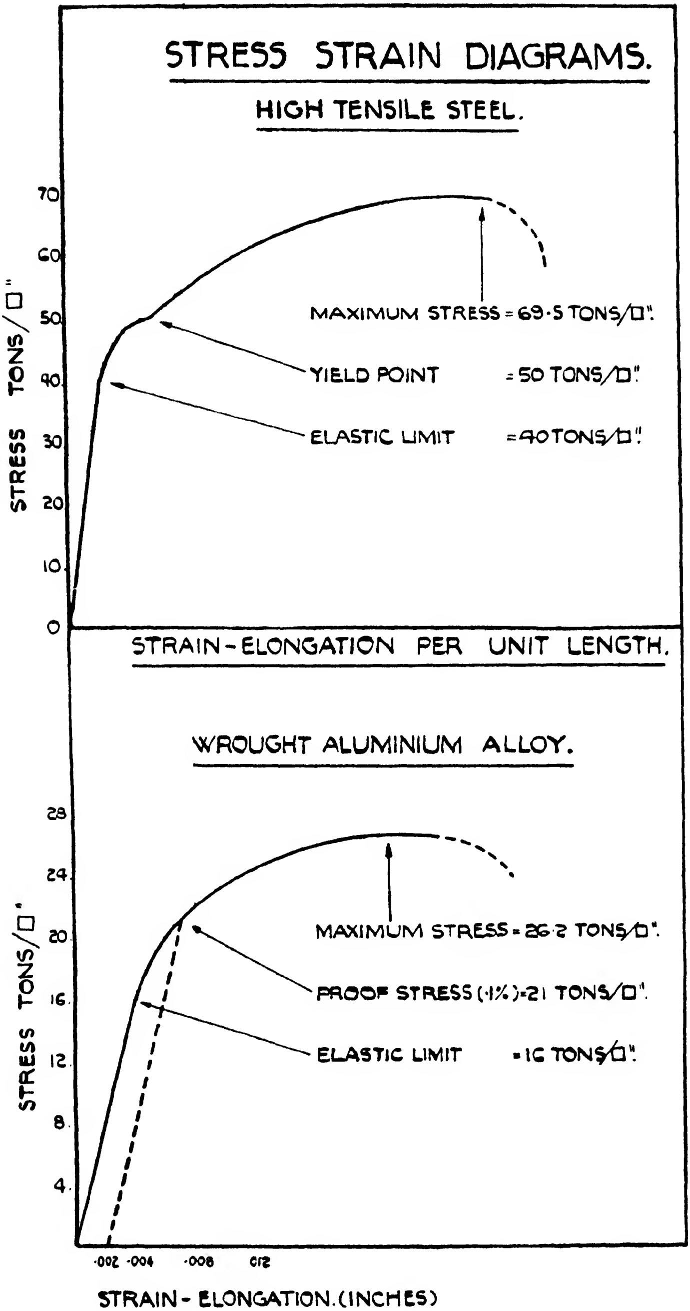

STRESS STRAIN DIAGRAMS.
HIGH TENSILE STEEL.
STRESS TONS/□"
70
60
50
40
30
20
10
0
MAXIMUM STRESS = 69·5 TONS/□".
YIELD POINT = 50 TONS/□".
ELASTIC LIMIT = 40 TONS/□".
STRAIN - ELONGATION PER UNIT LENGTH.
WROUGHT ALUMINIUM ALLOY.
STRESS TONS/□"
28
24
20
16
12
8
4
MAXIMUM STRESS = 26·2 TONS/□".
PROOF STRESS (·1%)=21 TONS/□".
ELASTIC LIMIT = 16 TONS/□".
·002 ·004 ·008 ·012
STRAIN - ELONGATION. (INCHES)

FIG. 1

Plate I. A Bronze Connecting Rod Bush which Extruded under Working Loads

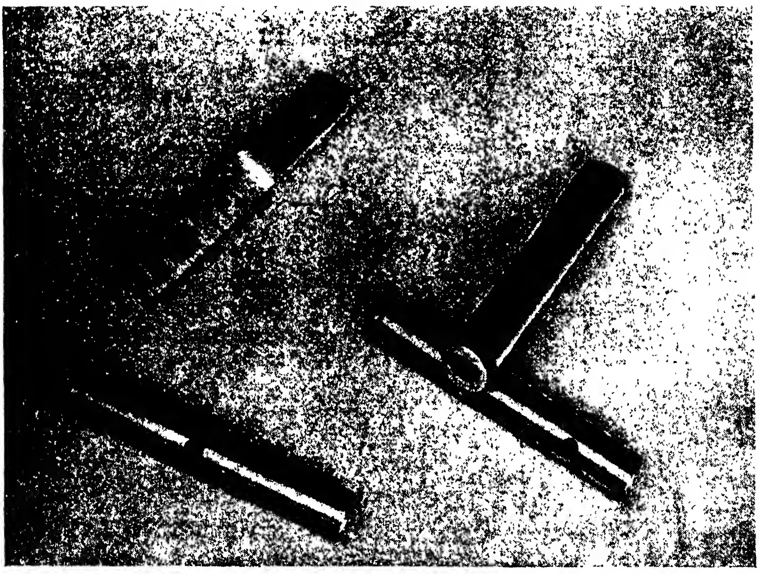
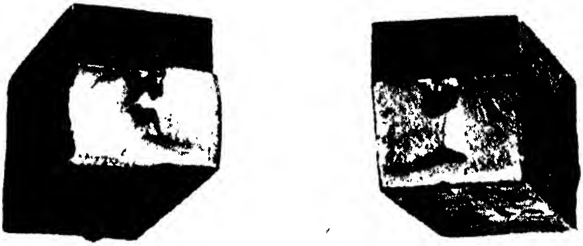


Plate II. $\frac{5}{8}$ in. Diameter Cast Phosphor Bronze Bar showing Blow Holes, Revealed only after Machining



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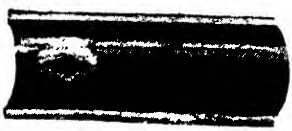


III

Plate IIIa. Two Fractures of Steel Bar Showing "Pipe"

Plate IIIb. Steel Bar Showing a "Lap," Formed in an Early Stage of Rolling

Plate IIIc. Sectioned Steel Water Pipe Showing Erosion Resulting in a Bad Water Leak

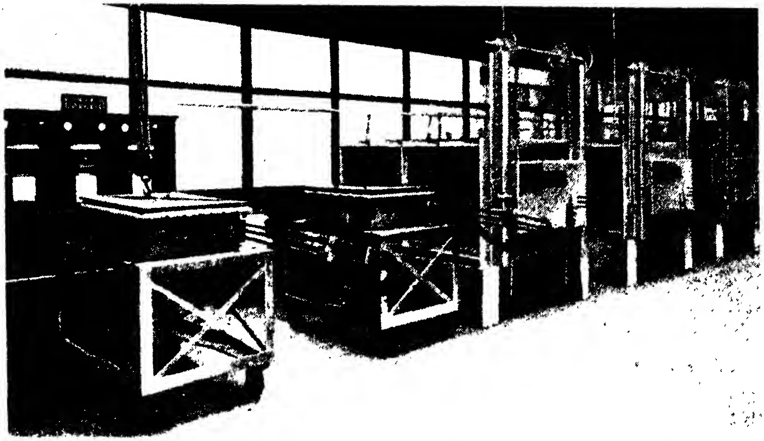


PLATE IVA. A BATTERY OF WILD-BARFIELD BOX NITRIDING FURNACES FOR VALVES AND SIMILAR SMALL PARTS

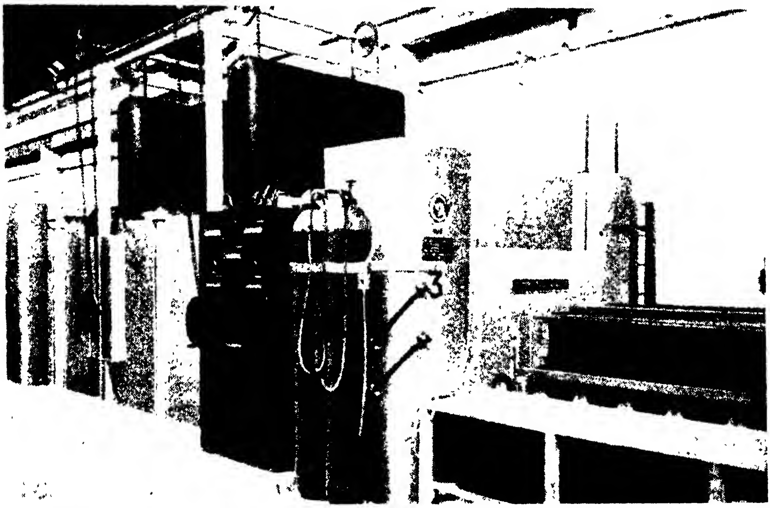


PLATE IVB. A GIBBONS WILD-BARFIELD DOUBLE ENTRY BATCH NITRIDING FURNACE INCORPORATING TWO INTERNAL DOORS, PROVIDING SEPARATELY CONTROLLED ZONES, PERMITTING THE USE OF VARYING SIZES OF BOXES, UP TO 21 FT. LONG, WITH THE MAXIMUM EFFICIENCY

The above furnaces include heat-resisting steel boxes, sealed with Al washers, and provided with inlet and outlet tubes for the passage of ammonia gas from cylinders fitted with automatic regulating valves, with fine adjustment to adequately control the percentage dissociation. The outlet pipe connects with a panel comprising bubblers, water reservoir and burette, but the Wild-Barfield automatic ammonia estimator is also available. To facilitate loading, roller topped trolleys are used, their height corresponding with similar rollers in the furnace hearth. These electrically heated furnaces produce consistent results because of the following features—

(1) Uniformity of temperature control, obtained within ± 5°, owing to the disposition of the elements in the roof, hearth, door, and side walls.

(2) The absence of flues ensures uniformity of furnace atmosphere.

(3) Automatic control of temperature and time is recorded on a strip chart.

Fans with baffles are sometimes incorporated in the boxes as an alternative to the static air equipment illustrated, to promote circulation of heat and ammonia.

the testing machine. Whilst this method is sufficiently accurate for routine testing, a more accurate determination would require the use of an extensometer. The yield stress is equal to the load in tons at the yield point divided by the original cross-sectional area of the test bar in square inches. The yield point is sometimes indefinite, particularly on non-ferrous materials, and for this reason certain specifications call for a "proof stress" instead. Proof stress is that point at which the stress strain curve departs, by a specified proportion of the original gauge length, from the straight line of proportionality. This may vary from ·1 to ·5 per cent. Typical stress strain diagrams are illustrated in Fig. 1, and the points referred to above are clearly marked with arrows.

Elongation and Reduction of Area are, to a certain extent, measures of the ductility of the material. The elongation is ascertained, after the test bar has been broken, by placing the two parts together and measuring the distance between the two centre pop marks. The increase in length expressed as a percentage of the original length, namely 2 in., gives the elongation. The reduction of area of the test bar will occur at the point of fracture, due to "necking" that will be noticed. This will be measured and expressed as a percentage of the original area. The ultimate stress is equal to the load in tons required to fracture the test bar divided by its original cross-sectional area in square inches.

Impact Test. This is a test for brittleness, and to determine capacity to resist shock, and suddenly applied loads. It gives a fair indication of the heat-treatment of steel, information which a tensile test does not necessarily show. Steel is composed of numbers of closely united crystal grains the closeness of which cannot be judged by the naked eye. Each grain has well marked cleavage planes along which breakage will occur when a bar is fractured. These cleavage planes show up as bright facets. A crack is either inter-crystalline if it travels round the crystal boundaries, or trans-crystalline if it travels across them as in the case of a fatigue crack. The fracture can be examined to ascertain whether the grain structure is satisfactory. A tough, fibrous structure indicates a correct heat-treatment, whereas a coarse, brittle, crystalline structure is undesirable.

It is important that a good grain distribution is obtained in a forging, and it is estimated that steel is 15 per cent stronger across the fibre than parallel to it. The arrangement of the fibres can only be determined, however, by macro-etching a polished surface.

Valves, gears, etc., are made either from stampings or upended bar, and the drop forge technique may be prolonged on many forgings in order to secure the maximum strength by providing a fibre flow in the direction that it is required.

The Izod machine is used in this country for these tests, and comprises a pendulum swinging in a vertical frame. The test piece is either of square or round section, and is provided with one or more notches, and must conform to the dimensions prescribed by the British Standards Institution. The test piece is held in a vice in such a position that one end is in the path of the pendulum, the notch facing the direction of impact. The test is made by releasing the pendulum

from a definite position. The energy absorbed in overcoming the resistance of the test piece to fracture is indicated by the reduction in swing of the pendulum after the impact, and is measured direct on a graduated quadrant in ft.-lbs.

Brinell Test. This apparatus, being in general use, is probably well known, and no description is, therefore, thought to be necessary. There are other machines, such as the Firth Hardometer, which function in a somewhat similar manner. A 10 mm. diameter steel ball is pressed into the material to be tested, under a load of 3,000 kilograms, and is maintained for a period of not less than 15 sec. The diameter of the impression so formed is then measured with a micrometer microscope. A test of this nature is sometimes sufficient to replace the ultimate stress figures for certain parts, and is useful in re-checking batches of forgings, or bars, which have been heat-treated together with one test bar. It is also valuable in exploring the uniformity of heat-treatment on large forgings and bars. The impression should be made only after the scale has been removed, otherwise errors equivalent to as much as 10 tons per square inch may easily result. The flat on which the impression is made should be smooth and sufficiently wide to prevent bulging, and the impression should be measured across two axes. It is possible to obtain an approximate idea of the ultimate strength of the material measured by multiplying the Brinell number by a conversion factor, as follows: For carbon steels ·23. Alloy steels ·22. High-tensile alloy steels ·21. Take as an example, an alloy steel with a Brinell number of 250. By using the appropriate factor ·22 we obtain an ultimate strength of 55 tons. I will now quote a rule of thumb formula which also gives approximate results. The ultimate stress equals the Brinell number divided by 5 plus 5. Taking the same example we have $\frac{250}{5}$ plus $5 = 55$ tons. It is possible with a Brinell machine to use a smaller ball with a proportional load, for dealing with soft non-ferrous alloys, or finished steel parts, where the larger impression might be injurious. Inspection Leaflet No. 406 (A.P. 1208) describes other hardness testing machines for use where case hardened surfaces have to be checked.

The various testing machines should be periodically checked for accuracy, particularly after one has been transferred to another place. The makers usually supply test blocks with hardness testing machines, in order that comparisons can from time to time be made.

The Izod machine should retain its accuracy provided that all working parts are maintained in perfect order.

Tensile testing machines are best checked by the makers, although there are a number of ways that a check can be effected. The following brief particulars relate to three methods—

(i) Two similar test bars are prepared from the same bar, one is pulled on the machine under check and the other on a machine known to be in good order, and the results compared.

(ii) A test bar is obtained which is known to have a straight stress-strain characteristic up to the yield point. A check within this range can accordingly be effected.

(iii) Known dead loads can be applied and comparisons made on the readings recorded on the beam, when in balance.

SHEET AND TUBES. These classes of material are normally delivered in the condition in which they will be used. If sheet has to be bent or made into pressings, or tube has to be bent or welded, some form of stress release thermal treatment may have to be done. In particular cases, heat-treatment after working may have to be carried out and then the relevant Specification must be referred to.

Tubes may be subjected to checks of chemical analysis, flattening and hardness tests, proof stress and tensile tests. For the last two tests the ends of the test piece are either flattened or plugged to provide a suitable grip in the testing machine. Inspection includes an examination for cracks and surface defects, straightness and dimensional accuracy.

Sheets may require checking for chemical composition, and may be subjected to single and reverse bend tests, proof stress and tensile test. For the latter, the test piece is cut so that the load is applied along the direction of the grain. Inspection includes an examination for surface defects, flatness and thickness.

NON-FERROUS MATERIAL. The quality is controlled in the foundry largely by—

1. The analysis of incoming ingots of virgin metal.
2. Daily analyses of the melts.
3. Tensile tests on test bars representing casts or separate castings.

Tensile test bars are cast in standard inclined sand-lined moulds and where they represent individual castings, are wired to them for heat-treatment and ageing. With general castings, that is to say smaller and less important ones, test bars are prepared for each cast up to a definite weight. Three test bars are normally provided, so that if the first one fails to meet the specification figures, a check can be effected. Slight variations in chemical composition may necessitate a change of heat-treatment temperatures.

Material Defects

Passing on to the various defects that must be looked for during the inspection of raw materials prior to, and during, manufacture, it becomes important in the case of hot-worked parts, such as forgings and stampings, to carry out some form of de-scaling, in order that a defect, if present, may be more readily detected. In this connection you are referred to Inspection Leaflet No. 415 (A.P. 1208), which details an approved method for removing scale and rust. Cold-worked material would be pickled. Dealing first with the ferrous materials, such as bars, stampings, and forgings, the defects that are normally encountered include folds, laps, hair cracks, pipe, roaks, slag inclusions, etc., and it may be of assistance if a little information on each of these defects is included at this stage.

HAIR CRACKS normally show up after a part has been machined, and occur in the direction of working the material. They are due to the elongation of minute blow holes or cavities originally in the structure. Unless the ground engineer has had some considerable experience in

dealing with this class of defect it would be his wisest course to reject any doubtful parts. On finished machined parts such as crankshafts, some discretion by the constructor might be permissible if hair cracks were suspected. It would be wrong to consider the acceptance of a part if hair cracks were intermittent throughout its length, or if cracks appeared in a radius or at a highly stressed position. In certain circumstances it might be permitted to remove a mark by very careful filing, provided the amount of metal removed was not more than several thousandths of an inch deep, and the crack was not more than $\frac{1}{8}$ in. long before it was removed.

SLAG INCLUSIONS. All steel contains non-metallic matter, but in ordinary proportions it is considered innocuous. The slag appears as fine intermittent lines distributed irregularly along the fibre flow of the material (see Plate VI).

Visible inclusions are probably more dangerous than others below the surface. Magnetic testing is very searching and may show up minute slag lines of an acceptable order, and for this reason discretion must be exercised. Furthermore, cracks show up readily on nitrided surfaces because they are not closed over when polishing, a condition which may occur with a soft steel.

The treatment of hair cracks is equally applicable to slag inclusions.

S. Fox & Co. use a quantitative method of expressing the cleanliness of their steel. Prepared specimens, taken possibly from three portions of an ingot, are micrographed. Approximately 30 fields are explored on each specimen and graded according to micrograph standards held for the purpose. By a simple formula, an inclusion number is established.

FOLDS AND LAPS usually appear on the outside of a bar or forging, and may be caused by flash edges being rolled or stamped into the material. They can usually be chipped out or removed without detriment to the part. Seams are sometimes caused by hard metallic matter which gets into the lubricant used when drawing small diameter bars through the dies.

ROAKS have the appearance of cracks, and may extend the full length of a bar. They are caused by gas or blow holes, which, having become oxidized, do not weld up again on forging, and are consequently drawn out on subsequent working. They may not be discovered until the parts are finally machined.

"PIPE" is caused by the caving in of the top of an ingot due to the contraction of the metal on cooling, and if present is due to insufficient cropping of the top of the ingot. With aircraft steels the centre of an ingot, where "pipe" might be present, is usually removed, and normally one need not anticipate a lot of trouble from this source. If it is present it may extend down the centre of bars throughout their whole length. In such cases the whole consignment should have a piece knocked off at both ends of each bar as a check.

ALUMINIUM. Foundry technique can be very complicated when producing parts for modern aero engines, as surplus metal has to be eliminated without materially affecting strength or promoting unsoundness: consequently skill and experience only can produce the required standard.

Gravity and pressure die castings are now used for many small parts, but sand castings are more general for the larger ones. Crank-cases, however, are produced as castings and also as forgings or stampings.

Clean scrap, such as risers, headers or unmachined scrap castings, is added to the virgin metal in agreed quantities. Scrap contaminated with cutting compound would be liable to introduce steam into the melt with resultant porosity. A melt must not be allowed to "stew" prior to pouring and just sufficient metal should be taken up in the ladle to fill the die or mould. Pouring should be continuous, and if two ladles are used the temperatures of the metal must be the same in each case. Excessive temperatures produce shrinkage cracks whilst low ones cause cold shuts, misruns, blow-holes and lack of definition. For thin castings then the high limit is preferable whilst for heavy ones the lower limit is better. Bare wire thermo couples of the immersion type will eliminate time lag errors.

A fully equipped foundry has inspectors who check the moulds with very accurate jigs and gauges at each stage, thus safeguarding, as far as possible, uniformity of wall thicknesses, etc., of the finished casting. They also check the temperature of the metal prior to pouring, the furnaces during heat-treatment, the pulling of test bars, etc.

CASTINGS. Most Al alloys are hot short. Si alloys, by virtue of their excellent fluidity, are exceptions. Small quantities of Cu cause hot shortness, due in part to the high casting shrinkage. Alloys high in Mg are also susceptible.

When fettling castings, care must be taken to remove all sand and core wires. A complicated casting may contain many wires in the moulds which may be difficult to see if they become lodged in passages and corners.

The more general defects met with on castings are laps, contraction cracks, flaws, blow-holes, porosity, short fettling, cold shuts, speckiness, thin walls, misplaced cores, and short bosses. Most of these defects can be readily understood by their names, and a lot can be learned by the periodical sectioning of parts rejected for any of these defects. Pressure tests should be made where possible, to check for porosity, and where doubtful patches appear on the surfaces of parts, prodding with a strong scriber may reveal cavities which would otherwise pass inspection. These cavities have a smooth interior, and are usually formed by steam pockets, the steam from damp moulds being unable to escape from the metal during solidification.

Speckiness in aluminium is a trouble associated with the foundry which always exists to some extent, but if it is very pronounced there is a risk of cracks developing when the part is stressed, due to the linking up of a number of the small holes, and such parts should be rejected. These holes are probably due to the release of dissolved gases present in the raw material. Specky metal is prone to inter-crystalline corrosion whilst magnesium alloys are comparatively free of speckiness. Chills tend to eliminate or reduce gas holing adjacent to heavy sections and the design of furnace pots should preclude the possibility of furnace gases reaching the surface of the melt.

Contraction cracks may occur due to a marked change in section of the part, and will not, of necessity, develop when subjected to engine running. In certain cases parts might be acceptable if the extremity of the crack was located with a small drilled hole. Contraction cracks may also be caused by the use of heavy chills adjacent to thin sections. Shrinkage allowed by the pattern maker for Al is approx. $\frac{1}{8}$ in. a foot.

Inclusions may consist of non-metallic oxides, impurities in the raw material, unskimmed dross from the crucible and moulding sand.

GRAVITY DIE CASTINGS. These are produced in permanent metal moulds which not only withstand wear better than wooden patterns but represent a big reduction in time if sufficient quantities are required. Weight can be closely controlled because of the accuracy of the dies. Anodic treatment can be applied after polishing or buffing whereas castings require machined-surface finish.

PRESSURE DIE CASTINGS. This process requires a machine for injecting molten Al alloy into a die at high pressure; consequently, unless a large quantity of castings is required, gravity castings or even forgings might prove to be more economical. The castings have smooth surfaces and dimensional accuracy necessitating the minimum of machining. Porosity and pinholes are prevented owing to the rapid cooling in the die whilst under pressure. Mechanical properties are improved and grain refinement is promoted.

The die should be designed to avoid sharp angles and rapid changes of section, as these would cause shrinkage cracks and cavities. In operation the dies should be pre-heated prior to the commencement of a shift to prevent chilling of the metal with consequent restriction of flow. This can be done either artificially or by producing a few scrap castings.

DROP STAMPINGS. A high standard of stamping technique is required to secure fibre flows in preferential directions with fine crystal structures and the minimum of ingot segregation, in such parts as pistons, cylinder heads, rotors, etc.: Al alloys do not flow readily and consequently require heavy blows to work the interiors of thick sections. Cavities do not weld up under the forging process and surface cracks must be removed.

Stampings may be faulty due to any of the following reasons—

(i) Offset due to the die becoming displaced.
(ii) Surface cracks occurring when attempting to reset.
(iii) Distortion due to forcible removal from the die.
(iv) Effect of scale left in the die.
(v) Working at too low a temperature.

FORGINGS. When dies would be costly or the number of parts required is small, forgings offer a practical solution. Extruded bar of suitable cross section is often used.

The manufacturing stages are as follows: Cut the bar up into suitable lengths. These pieces will travel with a process card, in suitable metal containers, through all the subsequent stages such as slow preheating in a saltbath, dummying, stamping, clipping, heat-treatment, hardness test, pickling, inspection, machining, etc.; the process card will contain information on all discarded parts.

EXTRUSION. This includes the pressing of Al alloy forgings by

shaping the external surface in a single or multiple piece die and the inner surface by a punch or blow.

Non-ferrous tubes and bars should be examined for die marks, seams, and spilleys, the latter being analogous to roaks, associated with steel.

Etching or pickling of light aluminium alloys may dangerously impair the fatigue resistance. Solutions containing caustic potash, caustic soda, washing soda, or acids should normally be avoided.

In the few cases where caustic soda is used for detecting cracks, at least 0·010 in. must subsequently be removed from all surfaces that have contacted the liquid.

Crack detection is also effected by means of anodic oxidation. This is a process, applied to duralumin and other Al alloys, excluding Mg and cast aluminium, to provide protection against intermittent contact with corrosive agents. A film is built up electrically to a thickness at least 100 times greater than the natural oxide film.

In one method the Al part to be processed is made the anode or positive in a bath of warm dilute chromic acid, while a stainless steel cathode is used. Prior to immersion, all grease and dirt must be removed with either petrol or a chemical cleaner, followed by a thorough wash in hot water. Agitation of the electrolyte is important and bubbles should not be allowed to form.

The electrolyte penetrates minute cracks and cannot be readily removed by washing. This will subsequently "ooze" out, leaving a dark stain, thus providing a valuable inspection check for the presence of undesirable defects in highly stressed parts such as rotors, bearing caps, etc.

A macro etch of burnt cast Al exhibits a crazy paving appearance and segregation can readily be detected in the laboratory, under the microscope. X-ray is used mainly to explore castings of new design and to guide the foundry before production commences.

Protective Processes (see also Section V of Appendix II)

The ground engineer should have a knowledge of the various protective processes as they play an important part in the life of an aero-engine, and attention is particularly drawn to the following.

CHROMATE TREATMENT. This is a protective process for magnesium alloy castings against corrosion. The parts are immersed in a bath containing potassium and ammonium di-chromate, ammonium sulphate and ammonia for from 30 to 45 min., the liquid being maintained at boiling point all the time.

The parts are subsequently washed and dried.

This treatment produces a dark brown film, and it is usual to protect this with a coating of cellulose enamel as the film is not very resistant to abrasion. The preliminary cleaning of the parts may be carried out by immersion for half an hour in a 2 per cent boiling solution of caustic soda, followed by a thorough washing in cold water.

The treatment should be applied only after the part is fully machined as otherwise a perfectly good seal against corrosion might be destroyed if machined surfaces, other than faced joints, were left exposed.

COSLETIZING. This is a chemical immersion process to protect external steel parts of an engine from rusting and corrosion. It is not unusual to treat such parts as airscrew hubs, cylinder barrels, induction pipes, brackets, and valve springs in this manner.

CADMIUM PLATING. This process is applied to studs and nuts, cylinder barrels, valve springs, etc., as a protection against corrosion and rusting. Full details may be found in D.T.D. Specification No. 904. Embrittlement following deposition of cadmium can be serious unless suitable heat-treatment, to expel the hydrogen from the steel, is subsequently carried out. This point becomes even more important if a preliminary acid pickling process has been employed for cleaning the parts, and where possible an alternative process should be carried out.

ENAMELLING. It is usual to stove-enamel aluminium cylinder heads, carburettor bodies, rocker covers, etc., whilst other parts are sometimes treated with cellulose paint. In either case it is advisable thoroughly to sand-blast the surface before applying the protective coating, in order to ensure satisfactory adhesion.

Full particulars of an enamelling process will be found in Inspection Leaflet No. 404 (A.P. 1208).

It is usual to give the part one or two coats of under-coating enamel, followed by a coat of glossy finishing enamel, the part being heated in the stove between each application, the time and temperature depending on the characteristics of the enamel, but in no case should the temperature exceed 170° C.

Exhaust manifolds, stub pipes, etc., except those made in stainless steel, are protected externally, and several processes are available for this purpose. The drawing will be the guide as to what process is required, and parts, either new or repair, should not be released until the requirements of the drawing in this respect have been complied with.

CALORIZING, FESCOLIZING, AND METALLIZATION. Calorizing is a process which has been used for manifolds, but the more generally recognized processes are "fescolizing" and "metallization." The first of these is an electrical deposition of metal, and for exhaust manifolds nickel deposition only is permissible.

With the metallization process the protective coating is sprayed on to the surface of the manifold, and whilst copper, zinc, and aluminium can be satisfactorily sprayed in this manner, only the latter is permissible for manifolds. It is sometimes referred to as "aluminizing."

Before the spraying actually takes place it is necessary to sand-blast the part to remove every trace of scale, grease, or moisture, and then the part should only be handled with rubber gloves until the spraying has been carried out. Adhesive tape is used for protecting threads and parts that are not to be sprayed. The manifold, or stub pipe, is then coated with bitumastic paint, subjected to heat-treatment, and then allowed to cool slowly. The temperatures recommended for this heat-treatment are such that in certain cases a jig may be required to correct distortion. See also D.T.D. Specifications Nos. 906 and 907.

If it becomes necessary to repair a manifold by welding, it is essential that the original protective coating be thoroughly removed to

ensure a satisfactory weld. In the case of fescolizing, sand-blasting will be found quite satisfactory, but in the case of metallization it will be found to be much more difficult, and a check should be made to see that the thickness of the material has not been materially decreased after the aluminium has been satisfactorily removed.

CHROMIUM PLATING. This consists of the electrical deposition of chromium on steel parts. It is done for appearance, as a protection against corrosion and to provide a thin surface to withstand abrasion.

With reference to corrosion, chromium is very immune from oxygen attack, but where thin coatings only are deposited, porosity may be experienced and a nickel underlay is sometimes provided.

Chromium is deposited on rocker pads, cones, and similar parts where abrasion is met and it is undesirable to scratch, brush, or polish the mat surface if accuracy is to be maintained. Polishing may easily break through the film, leaving the surface irregular and liable to pick up.

Before dispatching an engine or parts which are unprotected it is usual to apply a coating of Sozol, or, alternatively, temporary rust preventive to specification D.T.D.121.C. This is done either with a brush or by total immersion. In the former case colouring matter is usually added to indicate more clearly that all parts have been adequately protected.

Manufacturing Processes

Many of these processes call for special attention, and a brief reference to the more important of them will now be made. Brazing and silver soldering play an important part in the pipe lines of an engine, as the nipples are usually secured to the pipes by one or other of these methods. Push rod ends and other small parts sometimes depend on soldering for their location.

BRAZING. This is dealt with in Inspection Leaflet No. 405 (A.P. 1208), and it is important to note the difference between ordinary and special brazing spelter; the latter having a melting point sufficiently high to enable the finished part to be normalized in the case of dip brazing at any rate, but it should be pointed out that where a nipple is brazed to a steel pipe by heating with a blow lamp, there is a risk of the spelter running during subsequent normalizing. This is due to the fact that Grade A brazing metal has a plastic range very close to the normalizing temperature of the steel. It is not unusual in these cases to normalize the steel tube before brazing, taking care to remove all scale.

As regards inspection, a visual examination should be made, but in addition a part should occasionally be cut right through to ensure that the brazing metal has flowed satisfactorily. See Plate XXII.

The above leaflet also deals with soft soldering and soldering of stainless steel, and indicates the precautions necessary in cleaning the parts before treatment and the precautions to observe during the processes.

When soldering is stipulated in place of brazing, silver solder is normally used.

Acid fluxes should be avoided, but in any case, soldered parts must be thoroughly washed with an alkaline solution in order to neutralize any trace of acid, which, if not removed, would have a corrosive effect on the parts.

Some people recommend washing the part in boiling water only, followed by an oven drying at 150° C.

Inspection Leaflet No. 405 (A.P. 1208) deals with fluxes and mentions the tests for acidity applicable to the various forms of fluxes.

Suitable tests for jelly base fluxes can only be carried out satisfactorily in the laboratory.

WELDING. This is another process which must be considered, and it becomes important because there is no real method of inspection that ensures a 100 per cent job without destroying the part. Welding by oxy-acetylene flame is normally specified but electric welding is permitted for specific purposes. "X" ray has been used in connection with welding in order to check that continuous fusion has been effected all the way along a seam. Blow holes, cavities and cracks permit the ray to penetrate further into the steel and a darker patch will be indicated on the radiograph if such defects are present. Radiographs require very skilful analysis if they are to be of any real value, and the cost of the apparatus is prohibitive in many factories. Parts such as exhaust manifolds are quite unsuitable because of their bulk. Inspection Leaflet No. 145 (A.P. 1208) deals with the subject at length, but the following additional points are important and should be carefully noted.

1. Only those materials specified on the drawing should be used for welding. Normally the two materials to be joined would have approximately the same carbon content, which is usually not more than ·3 per cent. Soft iron wire is used for adding material to the weld. An excess of S in steel has a tendency to promote cracking under the fillet. Steel provides a fairly wide welding range temperature. In spite of this overheated steel is one of the great dangers, because the crystals can easily be increased in size many hundreds of times, although normalizing will usually restore the structure. For this reason a book record showing that parts have been normalized should be kept.

With a lap weld, a witness on the opposite side of the plate to the fillet is required, and in order that scale shall be avoided, the back of the plate should be protected with a suitable paint.

2. Certain of the austenitic steels are prone to "weld decay" if not given a correct heat treatment. It would be as well to avoid using this class of material, unless considerable experience has been obtained.

Elements such as Ti, Mo, W, etc., make steel less prone to weld decay, but if doubt exists as to the suitability of a particular class of steel, suitable tests are included in D.T.D. Specification No. 171A. Welding wire should be soft in preference to hard drawn, in order to reduce the risk of cracking resulting from rapid heating.

3. The welding of aluminium, inconel, etc., requires special technique, and only approved filler wires, fluxes, etc., may be used. Header tanks are sometimes built up of brass pressings, welded together. This should be followed by annealing.

4. With certain classes of work it is often desirable to pre-heat the part locally with reduced gas pressure. When welding, the tip of the cone of the flame only should come in contact with the metal, and a neutral flame should be employed, as an excess of oxygen is undesirable.

It should be realized that the temperature of the small white cone at the apex of the flame is probably 3500° C., and there is always a risk of decarburization near the surface of the steel. Periodical tests of the gases used should be made in accordance with Inspection Leaflet No. 145 (A.P. 1208).

5. A pressure test of the part which has been welded should be carried out where the design permits.

When repairing welded parts, such as exhaust and induction manifolds, stub pipes, etc., it is important to remove any protective coatings such as sprayed aluminium, otherwise the welding wire will not run satisfactorily and a poor weld would result.

The aluminium coating in the case of metallization, and the nickel coating in the case of fescolizing, can be removed by sand-blasting. In the former case, however, it is more difficult, and care must be taken to ensure that the thickness of the material is not impaired.

The repair of a crack by welding necessitates the removal of about ·005 in. to ·010 in. of metal from the surface to ensure freedom from the Al-Fe alloy and somewhat less in the case of the Ni-Fe alloy. The crack should be located at each extremity by drilling an $\frac{1}{8}$ in. hole. The edges of the crack should be chamfered, or better still removed, to form a narrow slot. The crack should then be "tacked" at intervals. If the crack starts from an edge, the first tack should be made there, and it will be found that distortion, as the rest of the seam is completed, will be prevented. The weld should take the form of a regular uniform fillet and on completion should not be filed or dressed in any way. Some manufacturers hammer the weld on a few parts such as induction pipes, where roughness on the inside might be detrimental, but authority in each instance is obtained from the Air Ministry.

Inspection Leaflet No. 39 (A.P. 1208) refers to test samples that have to be made by welders to ensure that they are fully competent at the work. The methods employed to prove that the samples are satisfactory are also quoted.

WHITE-METALLING. Referring now to the process of white-metalling aero-engine bearing shells, connecting rod big end bearings, etc., it is important to realize that the life of an aero-engine, between overhauls, is largely dependent on the ability of the white-metal to withstand the high loads imposed upon it, without undue distress and resultant disintegration, and for this reason every care has to be exercised at all stages in the process of white-metalling. It is not always possible for the ground engineer to obtain actual practical experience of white-metalling, but it is important that he has had the opportunity of supervising or checking every stage of the process, and that he is thoroughly conversant with the details of the procedure prescribed by the engine constructor, and which varies in minor respects only, in the various aero-engine factories. No attempt should on any account

be made to white-metal bearing shells unless the full equipment required is available. The tinning of the bearing shell is of the first importance, as the adhesion of the white-metal lining is largely dependent upon this stage. The tinning may have to be done two or three times, the last one requiring the use of the actual white-metal in place of the tin used on the two previous occasions. The following points in the process are also important.

1. Cleanliness at all stages must be strictly observed.

2. Approved fluxes and virgin white-metal only may be used.

3. Pyrometer control of the temperatures of the baths is essential, because they must be maintained within close limits of those specified. Any variations from the correct temperatures might result in either the oxidization of the white-metal, or the risk of working it whilst solidifying.

4. It is necessary to pre-heat the white-metalling jig, together with the rod or bearing shell to be filled. The normal practice is to immerse the parts in scrap metal, maintained at a temperature just below that at which the white-metal is poured. The white-metal should be skimmed before pouring, and an excess of metal in the ladle beyond that required to fill the bearing is undesirable. The molten metal should be vented with a wire in order to remove bubbles from the side of the shell, and additional metal should be added as necessary, to provide for the shrinkage as the white-metal solidifies. When connecting rods have to be re-metalled it is usual to run the old metal out by the total immersion of the part in a bath of molten scrap metal. This ensures that the temperature of the part is closely controlled, and is not brought within the temper brittleness range of the steel. This temperature is about 450° C., but, of course, varies with different high-tensile alloy steels.

5. When it is intended to re-metal bearing shells, a dimensional check should first be made, because the fine tolerance of interference between the bearing shell and the rod often makes re-metalling impossible, due to the fact that after lapping up the joint faces of the two halves of the bearing shell they may be undersize, and become scrap. If they are dimensionally satisfactory they can then be dealt with as previously described, except that a special jig may be required to accommodate them. Slight distortion may be noted when the white-metalling has been completed, but this can normally be rectified by gently tapping with a hide hammer, and the shells re-bedded satisfactorily into their rod.

6. A check to prove that the re-metalling has been carried out satisfactorily is important, and whilst a visual examination for porosity, and blow-holes, which may show up after machining, can be made, this is not enough. Certain types of bearings will respond readily to a ringing test when balanced on the fingers and gently tapped with a hide hammer. At the constructor's works a percentage of bearings are destroyed by subjection to a chipping test. There is, however, another test which can more easily be carried out. The finished bearing is immersed in hot oil for a few minutes and then wiped dry. It is then dusted with french chalk. After the bearing

has been allowed to cool, if any cracks are present they will be shown up by discoloration of the chalk where oil has been expelled. The test is equally satisfactory for detecting bad adhesion around the edges of the bearing.

See also Inspection Leaflet No. 138 (A.P. 1208).

7. The fabrications of lead bronze bearings are generally considered to be secret processes and details must therefore be excluded from these notes. The plant is elaborate and complicated, particularly where centrifuged bearings are concerned and the highest technique is called for.

The Cu and Pb, commonly forming a lead bronze lining, do not actually alloy but become a mechanical mixture. Minute bubbles of trapped gas may result in small blow-holes being revealed after machining. They are not of necessity detrimental if the metal is otherwise free from cracks and the adjacent metal is sound.

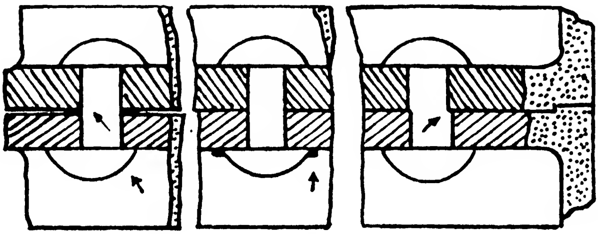


FIG. 2. EXAMPLES OF DEFECTIVE RIVETING

Premature crack formation is mainly due to tensile stresses produced either by shrinkage on solidification, or quenching causing contraction in the lead bronze layer. If up-to-date methods are employed, static casting has the advantage that the dendrite crystals then grow end on to the shell resulting in a high yield point. The finished machined thickness of the lining is important, as also is the bearing shell section.

Unsuitable crucibles might result in the presence of undesirable inclusions.

RIVETING. Where two parts are joined together by rivets through which a torque has to be transmitted, the importance of the riveting operation cannot be too strongly stressed, particularly if the parts are subject to suddenly applied loads.

The rivets must be a very good fit in the holes of both parts, and this will necessitate jig-drilling the rivet hole to close limits to ensure accurate spacing.

The two parts must be tightly clamped together to prevent any spewing or extrusion of the rivets between the two faces, and the rivet heads must be closed over either by a hand-snapping tool and hammer or a pneumatic hammer.

Care must be taken to see that the heads are square and not deflected to one side, and that there is absence of flash edges or cracks. The rivets

PLATE Va. TINNING A BEARING SHELL PRIOR TO POURING THE BEARING METAL

A = Flues from gas burners.
B = Pyrometer.
C = Gas-fired tin bath.
D = Tongs with locking ring, for handling shell whilst fluxing and dipping.
E = Tray with flux spread all over it.
F = Scalpel for fluxing the surfaces to be tinned.

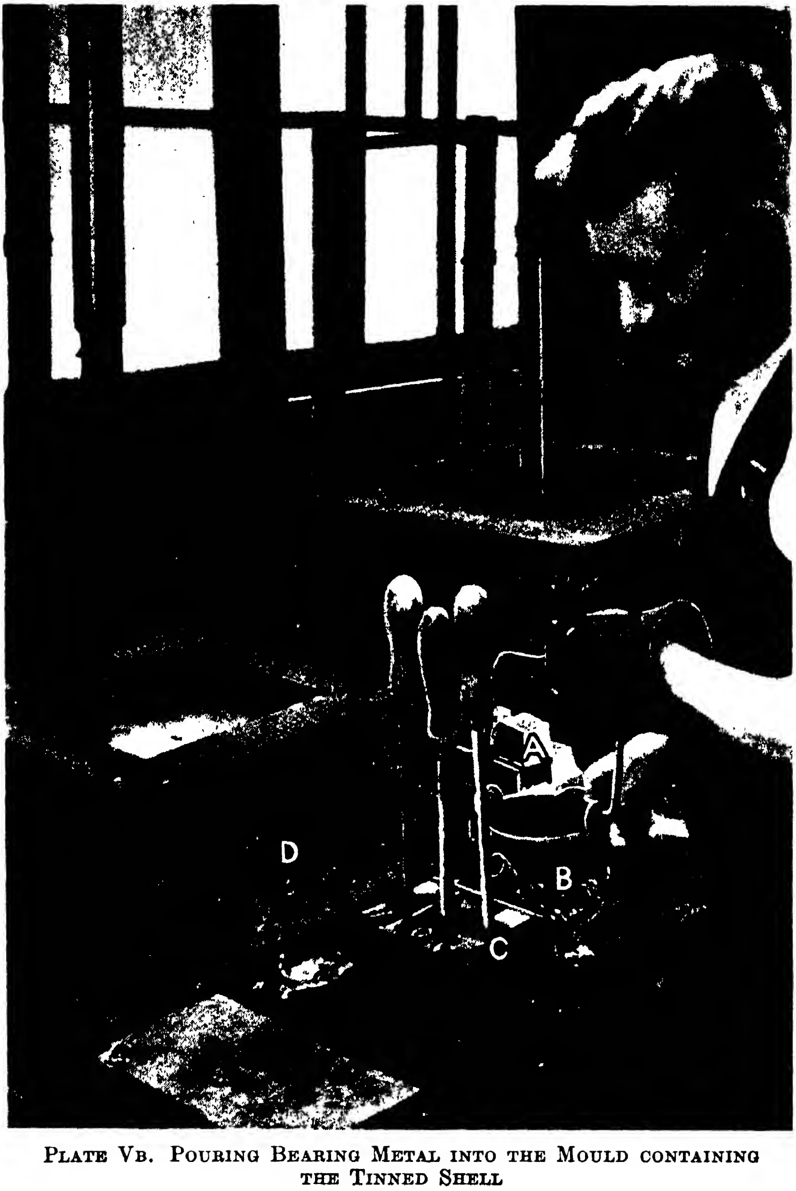


Plate Vb. Pouring Bearing Metal into the Mould containing the Tinned Shell

A = Blocks of virgin bearing metal.
B = Pot with spout from which the bearing metal is poured into the mould.
C = Mould comprising three detachable parts fitted with handles for ease of handling.
D = Gas-fired bath containing virgin bearing metal.

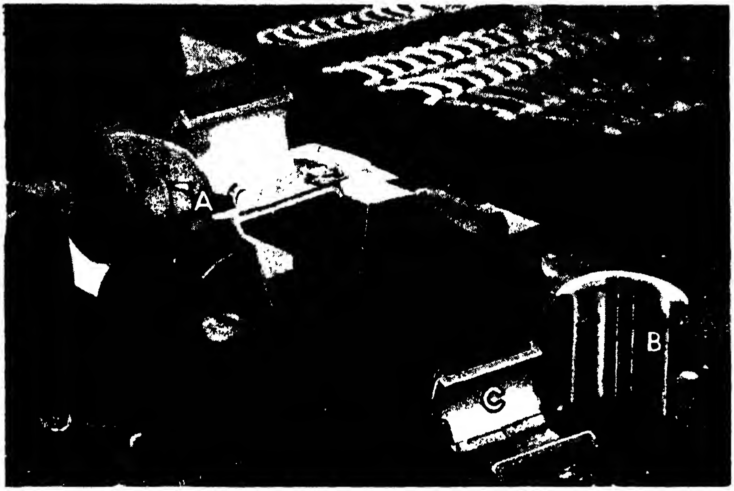


Plate Vc. Chipping Test on a Finished Bearing

A = Special flat-nosed chisel.
B = A shell which has satisfactorily withstood the test.
C = A shell which has failed.

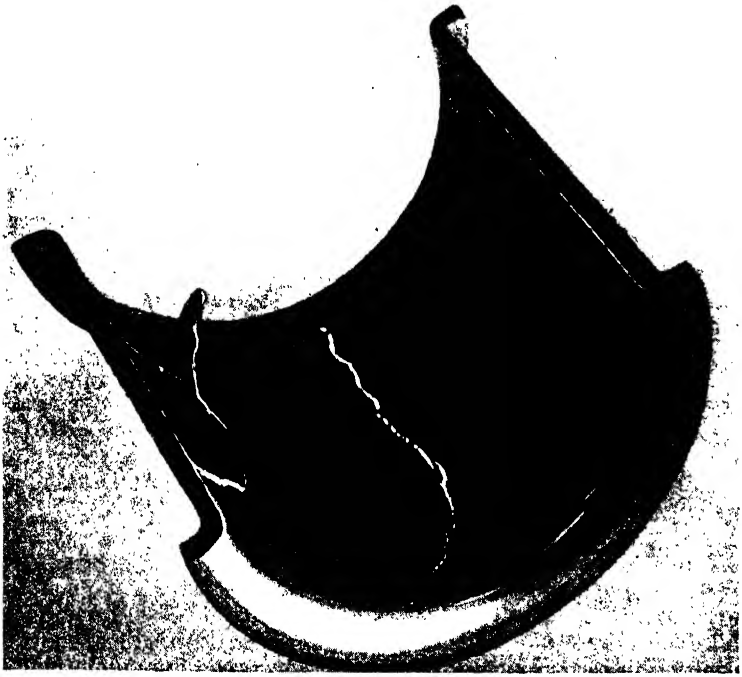


Plate Vd. Finished Bearing Shell showing Faulty Adhesion of the Bearing Metal

should be the material of specified and condition stated on the relevant drawing.

Pressure Tests

Pressure tests are carried out during stages of manufacture as well as on finished parts, and such tests are important, particularly in the case of aluminium castings, where porosity may always be suspected. The nature of these tests should be stated on the type drawings, but it is usual for parts to be subjected to air pressures when submerged in baths of hot or cold water as recommended by the constructors. Paraffin is sometimes substituted for water.

The following information will constitute a guide as to the approximate pressures to which parts are subjected, but in all cases the constructor's recommendations should, of course, be complied with.

Parts that are normally pressure tested at about 20 lb. per sq. in. include—

Carburettor body.
Induction casings.
Front and rear covers.
Cylinder head ports.
Fuel pump bodies.
Fuel pipes.
Primer pipes and rings.

Cylinder water jackets are tested from 25 to 50 lb. per sq. in. Aluminium cylinder headers up to 100 lb. per sq. in., and gas distributors and pipes at 200 to 400 lb. per sq. in. Piston crowns and cylinders complete are tested to from 400 to 600 lb. per sq. in., and a liquid is sometimes used instead of air. The cylinder test would, of course, show whether sparking plug and gas starter valve adaptors, valve seatings, cylinder head joints, etc., were tight. The test is satisfactory if the gauge pressure is held for the prescribed period. It is advisable to incorporate a filter in the circuit when using a liquid so that sand and dirt can be collected and the bath kept clean. Crankshafts complete with crank-pin plugs are subjected to tests at least 50 per cent in excess of the normal working pressures, and both hot oil and paraffin are used by the various constructors. Sumps, crankcase walls, and pockets, etc., are tested for porosity with paraffin, without pressure; the outside of the walls of parts to be tested are whitewashed, and any paraffin which penetrates, due to porosity, will be indicated on the whitewash.

Caulking, welding, or soldering of aluminium parts in order to attempt to correct a fault is not normally permissible. An agreed class of porosity in certain lightly stressed parts such as camshaft covers, might receive consideration and would be followed by an appropriate heat treatment. The filler would be of the same material as the part and the work would only be carried out by a thoroughly skilled operator. Plugging of parts in unstressed positions may be permitted in certain instances, and in such cases a duralumin plug is screwed tightly into a hole countersunk on both sides, and peened over. The diameter of the plug would in no case exceed the thickness

of the wall to be plugged. Blow-holes in face joints have, on occasions, been filled with solder, and limited discretion might be permitted in exceptional cases only. Boiled oil has been applied at the constructors' works to parts where slight porosity has been noted, merely as a precautionay measure in case porosity developed under running conditions.

There is a process which is in use by some manufacturers which undoubtedly ensures that the oil finds its way into all the pores of the aluminium. Briefly it is this: The parts to be treated are placed into a container, or tank, which is then sealed and air extracted. Linseed oil is admitted to the tank at a pressure of 70 to 80 lb. per sq. in. for about 30 min. The parts are subsequently removed, and dried in a gas oven for a number of hours at a suitable temperature.

This vacuum treatment ensures that most of the air previously in the pores of the aluminium is removed, the oil taking its place.

It is usual to treat carburettor float chambers with boiled oil as a protection against porosity, but care must be taken to ensure that all traces of oil are removed from the inside of the part by careful cleaning and scraping, and from petrol passages by reaming, etc. The cleaning of the surfaces should be carried out by lightly rubbing with pumice and emery. No surface metal should be removed, otherwise the hardened oil seal would be broken.

It should be remembered that parts that have been treated with oil cannot be anodically treated.

Before effecting pressure tests on headers or aluminium water jackets removed from engines that have had considerable service, it is important to thoroughly dry the part in an oven, as otherwise any porous places might withstand the normal pressure tests without showing signs of leakage, due to the capillary action of any water remaining in the pores.

Balancing of Parts

In order that reciprocating and rotating parts will function satisfactorily when assembled in an engine, it is necessary to ensure that they are correct to drawing so far as their weight and balance are concerned. In this connection, pistons are machined to within specified weight tolerances, and where, to facilitate manufacture and avoid useless scrap, a manufacturer grades pistons of similar design, it is usual to stamp the crowns with identification symbols in addition to their actual weights, so that when assembling a set of pistons into an engine only those of any one weight grade are selected. It must be clear that the tolerance of weight of a set of pistons will be the same in each engine, although the actual weights of the pistons may vary from engine to engine. For this reason, if it becomes necessary to renew a piston, steps should be taken immediately to ascertain the weight of the rejected one.

Connecting rods are manufactured to weight tolerances and the drawing normally requires the weight of each end to be determined separately in addition to a tolerance on the total weight. This check is made on a machine specially designed for this purpose.

Rotating parts such as crankcases of rotary engines, crankshafts, rotors, etc., are balanced statically, that is to say, they will remain at rest in any position when mounted so that they are free to rotate about their own axes.

It is also necessary to ensure that crankshafts, supercharger rotors, etc., are also in dynamic balance, for whilst a part may be in static balance when stationary, it may be out of balance when rotated, on account of the variation in density of the material or uneven distribution of the mass around the centre of rotation resulting in the presence of couples which, if not corrected, would cause excessive vibration. Constructors are normally equipped with suitable machines for checking dynamic balance.

Heat-treatment

The ground engineer must understand the various heat-treatments that material has to undergo, in order to transform it into the most suitable condition for use in an aero-engine, and we will deal first with the ferrous materials.

The ground engineer must understand what is meant by the term "upper critical point." This is the temperature at which a steel, on cooling naturally, commences to precipitate the carbon previously in solid solution in the form of cementite (iron carbide Fe_3C). The iron previously in "gamma" form becomes known as "alpha" iron.

Any change in constitution or rearrangement of the atoms constitutes a critical point. In most steels there are upper and lower critical points, but iron containing ·89 per cent carbon has only one. In this connection we may mention that with a straight carbon steel the upper critical range falls between 900° C. and 700° C., according to the amount of carbon present in the steel. With a critical point at 900° C. there can be no carbon present, but by adding carbon you progressively lower the upper critical range temperature until at 700° C. the carbon present is ·89 per cent. With alloy steels the temperatures are somewhat lower, and in any case the characteristics of each class of steel must be ascertained before correct heat-treatment can be carried out. A further study of this matter can be made by referring to textbooks on the iron carbon equilibrium diagram. A sketch of that part of the diagram which is required in connection with steels for aero-engines is shown in Fig. 3. Definitions of the terms will be found in the glossary at the end of these notes.

ANNEALING is often called for after a certain amount of cold working, that is to say, work done below a red heat, resulting in the material becoming considerably harder. Annealing is carried out by heating the part in an oven, and leaving to cool as slowly as possible. The temperature and time at which the part is maintained in the oven depends on the class and bulk of the steel, and the nature of the stress to be relieved. If the temperature is just above the upper critical range the structure of the steel is also refined. Annealing results in a finer structure than after normalizing, owing to the greater length of time in which the crystals have to rearrange themselves.

Annealing is also done to relieve internal stresses set up as in the case of steel castings.

Close annealing is a term applying to parts which are placed in closed tubes, or containers, for the annealing process, with the object of preventing the parts coming into contact with oxygen from the surrounding air, and thus avoiding the formation of scale and the risk of decarburization. Another process with the same object consists of purging the furnace with special non-oxidizing gas.

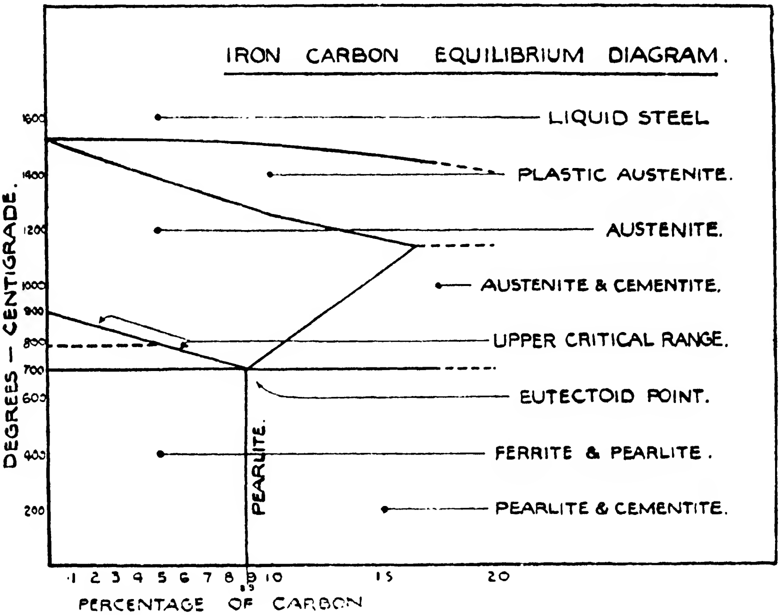


Fig. 3

When annealing stainless steel, temperatures may be as high as 1100° C., but not less than 1000° C., followed in some cases, by rapid cooling in order to avoid weld decay, which may occur if rapid cooling from between 800° C. and 400° C. is not carried out.

Normalizing becomes necessary when the material has a coarse crystalline structure, as in the case of a forging, a part that has been hot-worked or welded. To normalize a part it is necessary to heat the steel to a temperature not exceeding the upper critical range by more than 50° C. It is maintained at that temperature for about ¼ hr. and cooled freely in still air. This treatment has the effect of taking the cementite back into solid solution, and allowing it to crystallize out again in a finer state of division, and with a much reduced grain size.

The heat-treatment of a steel consists of hardening, followed by tempering. The hardening is carried out by heating the steel to its normalizing temperature, followed by immersion in water, oil, or air,

according to the class of steel and specification requirements. Most of the carbon in the iron is thus maintained in solid solution at ordinary temperatures. The more rapid the cooling, the finer will be the dispersion of the carbides and the harder the steel. On the other hand a drastic quench may cause internal stressing and cracks.

TEMPERING is carried out by heating the steel to a temperature below the critical range, say between 550° C. and 650° C. This has the effect of altering the degree of hardness and brittleness.

To make this point clearer, a set of tempering curves is included, for general guidance only, representative of a CrNi steel of the S.11 class, and it will be understood that curves for other steels will vary according to the carbon content and the presence, or otherwise, of alloying elements. (See Fig. 4.)

These curves are compiled by carrying out a series of mechanical tests on a number of similar test bars, each one hardened in a similar manner, but tempered at different temperatures.

An examination of the curves will show that with this class of steel the impact figures are low at tempering temperatures between 250° C. and 450° C., and that high maximum stress figures can only be obtained at the expense of the impact values. In other words one has to make a compromise in order to meet specification figures, and this can only be done by a careful selection of the tempering temperature.

If the temperature at which normalizing or heat-treatment is carried out exceeds the upper critical range by more than 50° there is a risk of burning the steel, in which condition the crystal grains are split apart and cannot be restored other than by re-melting.

The following points may be informative in effecting heat-treatments—

(i) Large forgings and stampings should be amply supported and the furnace should be charged so that all parts get uniform heating.

(ii) With large forgings mass effect must be considered and the period of heat-treatment should commence only when the whole has attained the required temperature. This should be done by the application of a uniform temperature gradient, thus ensuring the solution of all the elements, for while C steels are good, those containing Cr, Mo, V, W, and Co are sluggish and the "hardenability" of steel depends on the complete solution of the elements.

Furnace temperatures must be pyrometer controlled because a red heat, for example, when judged by the eye, can easily vary from 600° to 800° C.

(iii) Mass effect must also be considered when quenching and local heating of the coolant should be avoided by agitation or other means. An adequate volume of coolant must be provided and in the case of oil, vapour pockets of low thermal efficiency may form on the part if the oil thickens up, resulting in non-uniformity of hardness. The quenching tank should be adjacent to the furnace so that no loss of temperature occurs during transfer.

(iv) Quenching cracks occur at sharp corners, grinding and tool marks, non-metallic inclusions, and also in coarse structures. The

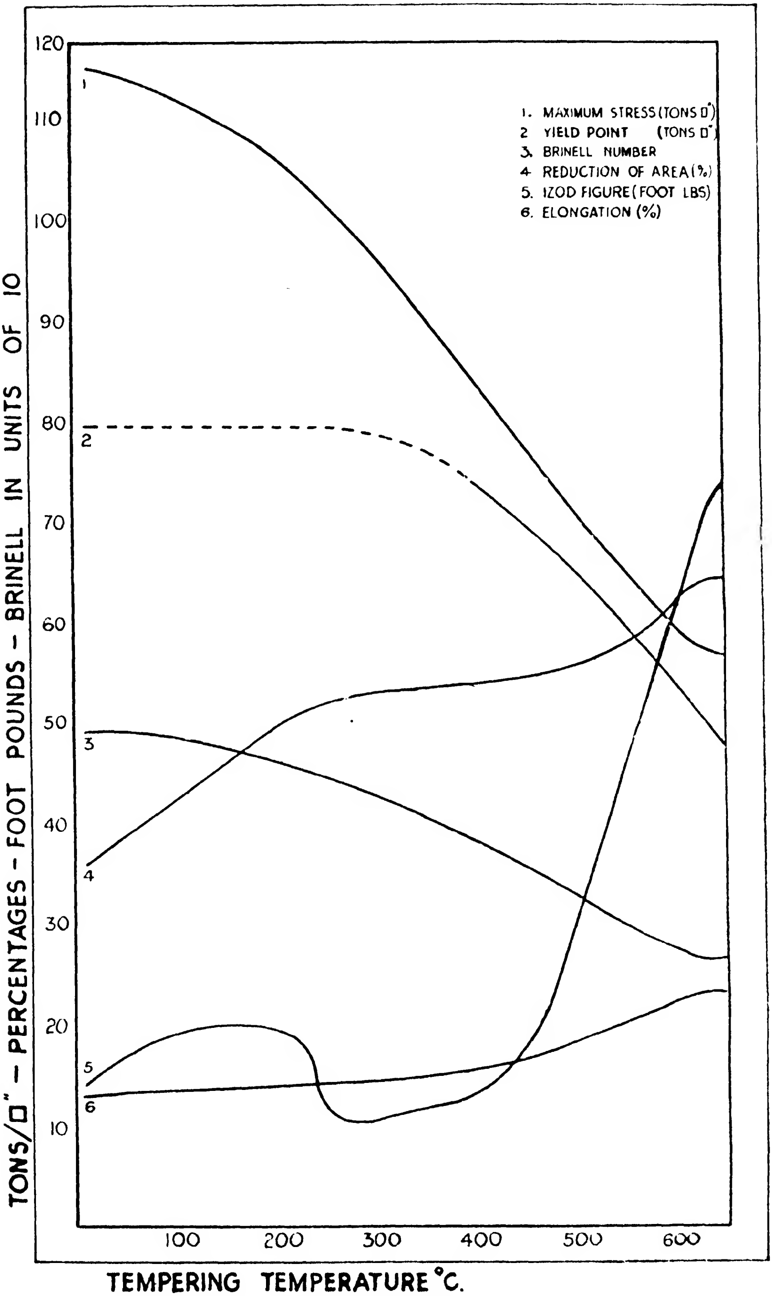


Fig. 4. Tempering Curves for Steel

cracks are on the surface and do not of necessity follow the flow lines of the material. There is no decarburization or scale formation. Cracks may show up after a lapse of days.

(v) Long forgings, such as camshafts, are often cooled vertically to minimize distortion, whilst large light gears may be quenched under a press for the same reason. Warpage is more likely to occur with steel having a high C content and is also influenced by uneven heating.

(vi) The presence of scale in irregular patches on the surface of a part when quenching, may result in only partial conversion of the steel from Austenite to Martensite, the patches under the scale being either Sorbite or Troostite. Such a condition might set up internal stresses sufficient to start a crack. Scale formation can be reduced by a coating of Graphite whilst deposition of Ni practically eliminates zoning. In addition, the furnace doors must be a good fit and should only be opened for charging. In regard to flash plating with Ni, if a specified thickness is required, a pilot test piece should be inserted.

CASE-HARDENING is carried out to obtain a material with a very hard, good-wearing exterior, or case, together with a very tough interior, or core, which will resist shock. The process consists of the migration of C into the surface of the steel in the form of CO gas which is split up to give atomic C. This will only occur at a temperature above the upper critical range of the steel when the ferrite is in the austenitic state.

The usual process employed on aircraft parts is known as box carburizing. The steels used contain between ·1 and ·2 per cent of carbon. In addition, certain alloys are added if the core is required in a stronger condition.

Nickel enables oil quenching to be substituted for water, and this less drastic treatment not only minimizes the risk of surface cracks appearing after grinding, but reduces the rejections due to distortion.

The more important points in the process of case-hardening and requiring attention are—

CARBURIZING COMPOUND. A large variety of substances is used, and apart from proprietary mixtures, such as casenit, etc., there are charcoal, barium carbonate, and charred leather.

The compound should be free from dust and sulphur, and should not produce any ash which fuses at the carburizing temperature. The carburizer, if in the form of pellets, permits the gas to circulate freely. New compound should be added to the old mixture at regular intervals, but spent compound should be placed in still air to regenerate.

The rate of producing carbonaceous gases varies with the various compounds, and experience only can determine the right temperature for the oven and the period that the part has to remain there.

Nickel steels take longer than plain carbon steels for the occlusion of an equivalent amount of carbon.

PREPARATION OF THE PART TO BE CASED. The surfaces that require hardening should be thoroughly cleaned, and those that do not require

hardening should be protected either by a coating of suitable enamel, copper deposition, asbestos string, clay, etc.

The articles should be so packed in metal boxes that there is at least 2 in. of carburizing material between them and any part of the box or lid. They must not touch each other, otherwise soft spots may occur.

The lid should be luted with clay to prevent gas leakage.

CARBURIZING. The box is heated up to the required temperature and retained at that temperature for the specified period. As a guide to this, it may be taken that a depth of case of 1 mm. (·040 in.) would be obtained in from 4 to 6 hours, the temperature being about 900° C.

The box is then allowed to cool slowly in order that the merging of the case into the core may be as complete as possible, thus avoiding the hard line of demarcation that is occasionally noticed due to an abrupt transition. The risk of "exfoliation" or "peeling" of the case is also minimized, but fatigue in the graduation zone may occur if the case is thin.

HEAT-TREATMENT. It is desirable to clean the parts after removal from the box, and this can be assisted by sand-blasting.

The long heating in the box at an elevated temperature results in the production in the core of a coarse structure. It therefore becomes necessary to refine the core by re-heating the material to a temperature about 900° C., and quenching. This temperature, however, is much too high for the case, and thus a second heat-treatment at about 760° is required, after which the material is again quenched. This second heat-treatment and quenching also improves the condition of the core. The refining process does not require any period of soaking before quenching, and even the final hardening does not require any undue soaking.

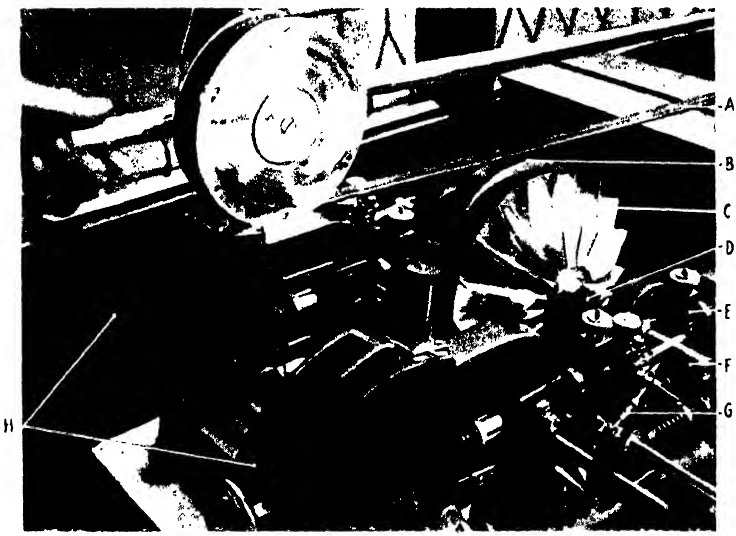
TEST BARS. Two bars of material, identical to the parts, will be prepared. One will be included in the box for carburizing and heat treatment, the other will receive heat treatment only, after which a standard test bar will be prepared from it and the physical properties, which would be representative of the core, ascertained.

The other test bar will be fractured and examined. A succession of light blows is preferable to a sudden impact. The core should show a close-grained fibrous fracture, and the case a characteristic silky smooth appearance. With high alloy steels, case depth may be difficult to determine as the core may show a structure having a grain size differing only slightly from that of the case. In these instances, grind the end of the broken bar, then etch with HNO_3 in alcohol and the depth of the case will become much more definite.

There is also another method in which suitable heat treatment is given to the bar to produce a certain colour change. If the core is caught at brick red, the case will be blue.

STRAIGHTENING. Slight distortion can normally be rectified during the grinding process, and it is undesirable to resort to straightening because there is no guarantee that any setting will be permanent, and, furthermore, visual examination might not be sufficient to detect any cracks which might easily commence.

PLATE VI. INCLUSIONS IN STEEL
(As seen on a finished surface under a 5 to 1 magnifying glass.)



By courtesy of *Messrs. Armstrong-Siddeley Motors, Ltd.*

PLATE VII. IMPELLOR BALANCING MACHINE

A is a rotating belt providing a friction drive to the mechanism, when lowered to come into contact with the fly-wheel *B*.
F is a rotating shaft, which is mounted on ball bearings and carries the impellor *C*. The nut *D* secures the impellor on the shaft. The mechanism *E*, comprising the shaft and its bearings, is spring mounted, and any error in balance is transmitted *via* the mechanism *G* to mirrors, which reflect beams of light on to the two scales *H*.

Some discretion might be permitted by the constructor in certain cases if followed by a magnetic test.

For examples, the straightening of a soft shaft with an integral case-hardened gear at the end, or the straightening of parts prior to heat-treatment.

Camshafts for in-line engines which become bowed are sometimes straightened after annealing at from 150° to 200° C. It may be necessary to deflect the centre of the shaft about three times the amount to be corrected. This should be done by the application of a progressive load, and not a suddenly applied one.

NITROGEN HARDENING. This is a form of surface hardening which is carried out to a limited extent on crankpins and journals, the inside of cylinder barrels, valve stems, etc., and parts where local shock loadings do not occur.

The steel used for this process is of special chemical composition, and may include 1 per cent of aluminium but no nickel, as its presence would reduce the impact value. The steel is heat-treated in the usual manner prior to surface hardening by this process, and parts which have not to be hardened are protected in a similar manner for case-hardening, except that copper plating is unsatisfactory. One process, briefly, is to pack the parts to be hardened in an air-tight box, through which anhydrous ammonia gas is passed. Impregnation of atomic H forms hard nitrides of the elements in the steel. The box is maintained at a temperature between 470° and 500° C. and the depth of penetration is dependent on the class of steel and the time the process is in operation. If the part is in the oven for 75 hours penetration of from ·010 in. to ·015 in. deep may be expected.

The following points should be noted—

(i) The box must be free of air otherwise the uniformity of penetration cannot be ensured. Tests of gas leaving the box must be made at intervals. This is done by passing the gas through H_2O in a calibrated burette. Free ammonia will be absorbed while N and H will pass over and the disassociation can then be estimated.

(ii) Part machined, heat-treated parts can be nitrided without risk of distortion, it being only necessary to leave a grinding allowance on the surface nitrided. This is necessary because the process results in the growth of a relatively soft outer layer about 0·001 in. thick which, if not removed, is always liable to crumble. If a lapping machine is available, grinding can be dispensed with.

(iii) The process can be repeated on the same part without detriment. This might be necessary on a crankshaft, if a crankpin became damaged and required reducing in diameter, in which case all pins would have the nitriding entirely removed, otherwise spalling is possible.

(iv) Sn offers protection against penetration of the oven gas. The coating should be as thin as possible so that only that retained by surface tension is left. This avoids the risk of excess metal dropping off and falling on to vital parts in the box.

(v) Steels, except those containing Ni, respond in some degree to hardening by this process.

(vi) Nitrided surfaces, if lubricated, are free from lead attack.

(vii) Parts should be supported in the oven at positions where penetration is not required.

(viii) Some manufacturers consider a stabilizing treatment beneficial to the steel prior to nitriding. It is important that there shall be no decarburization on a surface to be nitrided.

HEAT-TREATMENT OF NON-FERROUS MATERIALS. Aluminium is probably the only metal under this heading which is subjected to heat-treatment to improve its physical properties. The improved properties are dependent largely on the presence of one or more of the following alloying elements: Cu, Ni, Mn, Mg, Fe, Ti, etc.

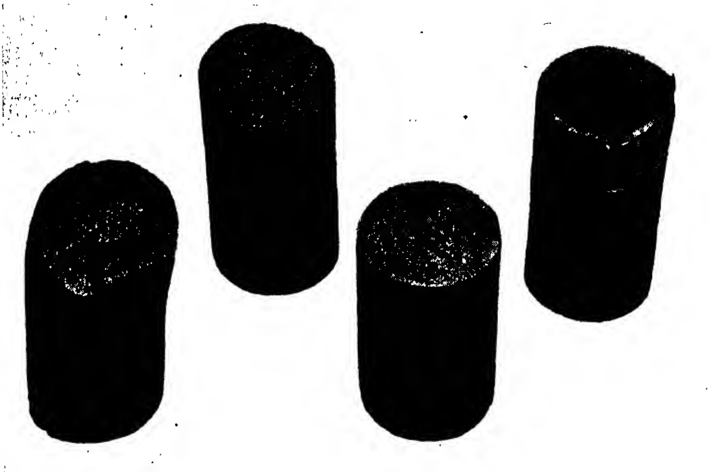
It has of course been current practice for many years to "Season" castings, both large and small, at various stages of manufacture by annealing, with a view to relieving casting stresses and eliminate the possibility of distortion which might otherwise develop. Aluminium with a high silicon content has considerably helped the foundry in eliminating some of their difficulties in regard to intricate castings and has also provided material with properties offering considerable resistance to corrosion. Magnesium alloys, whilst being very light and consequently useful in aero-engines, are not resistant either to salt water or atmospheric corrosion. The properties can be much improved by a high temperature treatment.

Aluminium alloys are now obtainable in the forged and wrought condition, but no matter in what form the material is available, the physical properties are low and unless it is subjected to some form of thermal treatment to improve these properties, is unsuitable for the manufacture of highly stressed parts, such as pistons, connecting rods, cylinder heads, crankcases, etc.

The various elements or hardening constituents added to aluminium can be taken into solid solution at elevated temperatures in the same way that carbon and other elements can be absorbed in steel. There is however this difference. On quenching steel the solid solution is maintained at room temperature, but in the case of aluminium alloys they are not stable. In addition, super-saturation may occur as the part or material cools and precipitation of the particular alloyed constituent may result. In other words aluminium can absorb and retain more of the constituent at elevated temperatures than at room temperature.

The precipitation or "age-hardening" takes place very slowly at room temperatures but can be accelerated with some alloys if subjected to low-temperature treatment between 100° C. and 200° C., after which the material becomes appreciably harder and the physical properties are much improved.

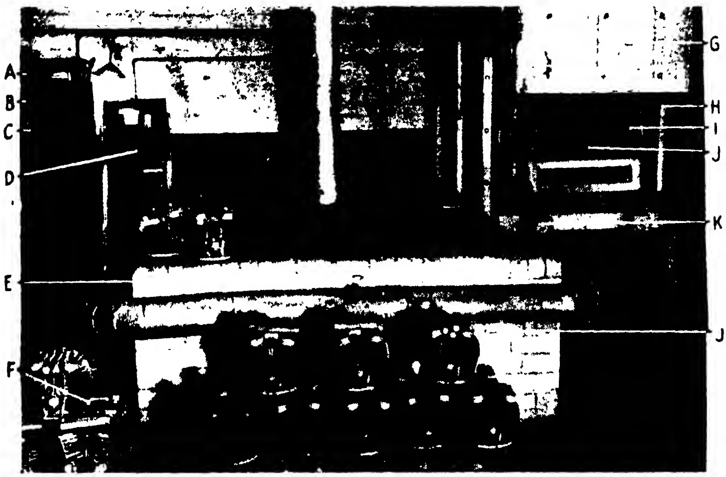
The high temperature treatment, sometimes called normalizing, can be done either in an electric furnace or a salt bath. The temperature control is important, particularly in the case of magnesium alloys and duralumin, as the temperatures approach closely to those of the fusion point of the constituents. The age-hardening can be carried out in a gas-fired oven. With regard to the use of a salt bath, every care must be taken to see that the part is entirely immersed and heated uniformly.



A B C D

PLATE VIII. FRACTURED TEST BARS OF STEEL TO BSS. 2.S.14 SHOWING STAGES OF CASE-HARDENING

A = Normalized bar as received. (Note coarse structure.)
B = After carburizing at 910° C. for 8 hours and cooling in box.
C = After refining the core at 900° C. and quenching in cold water.
D = After second heat treatment at 770° C. and quenching in water.



By courtesy of *Messrs. Armstrong-Siddeley Motors, Ltd.*

PLATE IX. HEAT TREATMENT OF CYLINDER HEADS

A = Foster pyrometer. (Thermo couple in top of furnace.)
B = Wild Barfield temperature control.
C = Venner time switch.
D = Cambridge recording pyrometer. (Thermo couple in base of furnace.)
E = Water bath for quenching parts after heat-treatment.
F = Cylinder head, showing cast on bridge for controlling distortion.
G = Wild-Barfield electrically-heated furnace.
H = Electrically-heated elements in walls and door of furnace.
I = Asbestos sheets to eliminate radiation from the elements.
J = Test bars (two with each head).
K = Switches, which start circulating fan in top of furnace, on closing door.

Approximate heat-treatments for several aluminium alloys in general use, are given below.

Duralumin: Soak from 480° C. to 500° C. for from a quarter to three hours, according to the size of the piece and quench in water or oil. Age-harden naturally for four or five days.

Notes. (i) Accelerated age-hardening is not permitted. It would respond to this treatment but if carried out too quickly, that is to say at too high a temperature, would leave the material brittle.

(ii) The temperature of the piece must be not less than 480° C. at the time of quenching, so the temperature when it leaves the oven must be high enough to allow for any drop in temperature during the transfer.

(iii) The upper temperature must on no account be exceeded.

(iv) Any cold work after heat-treatment may entail a re-heat-treatment of the piece.

(v) If a salt bath is used, the pieces must be thoroughly washed in water afterwards. See also Inspection Leaflets Nos. 408 and 414 (A.P. 1208).

"*Y*" *Alloy:* Soak from 500° C. to 520° C. and quench in boiling water followed by natural ageing for four or five days or accelerated ageing by immersion for two hours in boiling water.

Note. Physical tests can only be made on completion of the full period of ageing of the test bar.

Hiduminium: Soak from 500° C. to 535° C. for from two to four hours and quench in water. Age-harden from 155° C. to 175° C. for from fifteen to twenty hours and quench in water.

Note. The temperatures and times quoted will vary according to the particular variety of this material. It will also be noted that low temperature treatment is necessary, as the material does not age-harden quickly enough, naturally.

Material to R.R. Specification No. 50 (D.T.D. 133B), which is one of the Hiduminium series, is used for sand and die castings and attains its physical properties with low temperature treatment only, thus avoiding dangers of cracking and distortion associated with the high temperature treatment. The heat-treatment is to soak at from 155° C. to 170° C. for eight to sixteen hours, followed by quenching in air or water.

Heating of Monel and Inconel should not be carried out in a furnace fired by solid fuel as S, if present, is readily absorbed at and above red heat and produces surface embrittlement.

Gas heating is suitable and even then no unburnt fuel should be permitted to contact the hot surface of the article. A slight oxidizing atmosphere is preferable if S is present, but slight scaling may then be inevitable. Heat should only be applied to raise the temperature of the article uniformly throughout and "soaking" time should be reduced to a minimum.

Close control of all temperatures during heat-treatment processes should be maintained by means of pyrometers, preferably of the automatic recording type. All pyrometers should be checked by Sentinal salts or master pyrometers at regular intervals. A check must also be

made of the zero settings and connections and terminals should be periodically inspected for tightness.

Many thermo couples incorporate wire which may get oxidized and corroded, eventually becoming reduced in thickness. A spare couple with its own compensating leads should be held in readiness for replacement.

The portion of the sheath of the pyrometer inserted into the furnace is susceptible to cracking and may require frequent renewal. The following is a guide to the maximum operating temperatures of metal sheaths—

Wrought or cast iron	700° C.
18/8 stainless steel	850° C.
Nickel	1,100° C.

All records of heat-treatment should be correlated with the various batches of parts heat-treated, in the same way that test bars must be correlated with the part, or batch of parts, heat-treated. (See Plate IX.)

Dimensional Check

We now come to the inspection of parts, both during manufacture and prior to assembly in an engine, and it is important that the ground engineer has had experience in the manipulation of the various measuring instruments such as the micrometer (reading in fractions of ·001 in.), the Vernier Height Gauge, the Vernier Slide Caliper Gauge, the Depth Gauge, the Dial Indicator, etc., and the use of gauges for checking linear dimensions and plain screwed diameters. He should be familiar with English and metric systems of measurement, and understand the tolerances quoted on drawings. He should be reasonably conversant with the limit system applicable to the particular engine in which he is interested. Some manufacturers have their own system of limits for plain dimensions, which in most cases will be found to be an amplification of the Newall system, whilst others have adopted the British Standards Institution system of limits and fits.

The Newall system is founded on a "hole" basis which provides for A and B classes of hole over a range of from 0 in. to 6 in. Various fits are obtained by mating these holes with shafts in F, D, P, X, Y, and Z classes; the various combinations providing force, driving push, and running fits. The system is somewhat restricted in range as compared with the B.S.I. Limits and Fits for Engineering (Report No. 164, 1924). The latter provides a greater range on the nominal sizes and the tolerances applied to each. The main principle is, however, the same in that the various fits are obtained by varying the fits of the shaft to a given set of holes. Limits are referred to as "unilateral" and "bilateral." The unilateral system has the nominal size as the low limit of the hole and the tolerance is all in one direction, whereas with the bilateral system the nominal size lies between the high and low limits of the hole, the tolerance is therefore in both directions. This system provides twenty-eight varieties of fits as compared with eleven sizes in the case of the Newall system.

The more important functions of a view room will now be mentioned.

1. Special gauges and fixtures, suitable for checking the major components, must be provided to ensure interchangeability of parts. These fixtures, together with the surface table on which they are to be used, must be accurate to within the limits of the work to be checked. Standard "go" and "not go" plain and screw gauges must be provided for all other dimensions to ensure conformity to the respective drawings. (See Notice to Aircraft Owners and Ground Engineers No. 16 of 1932.)

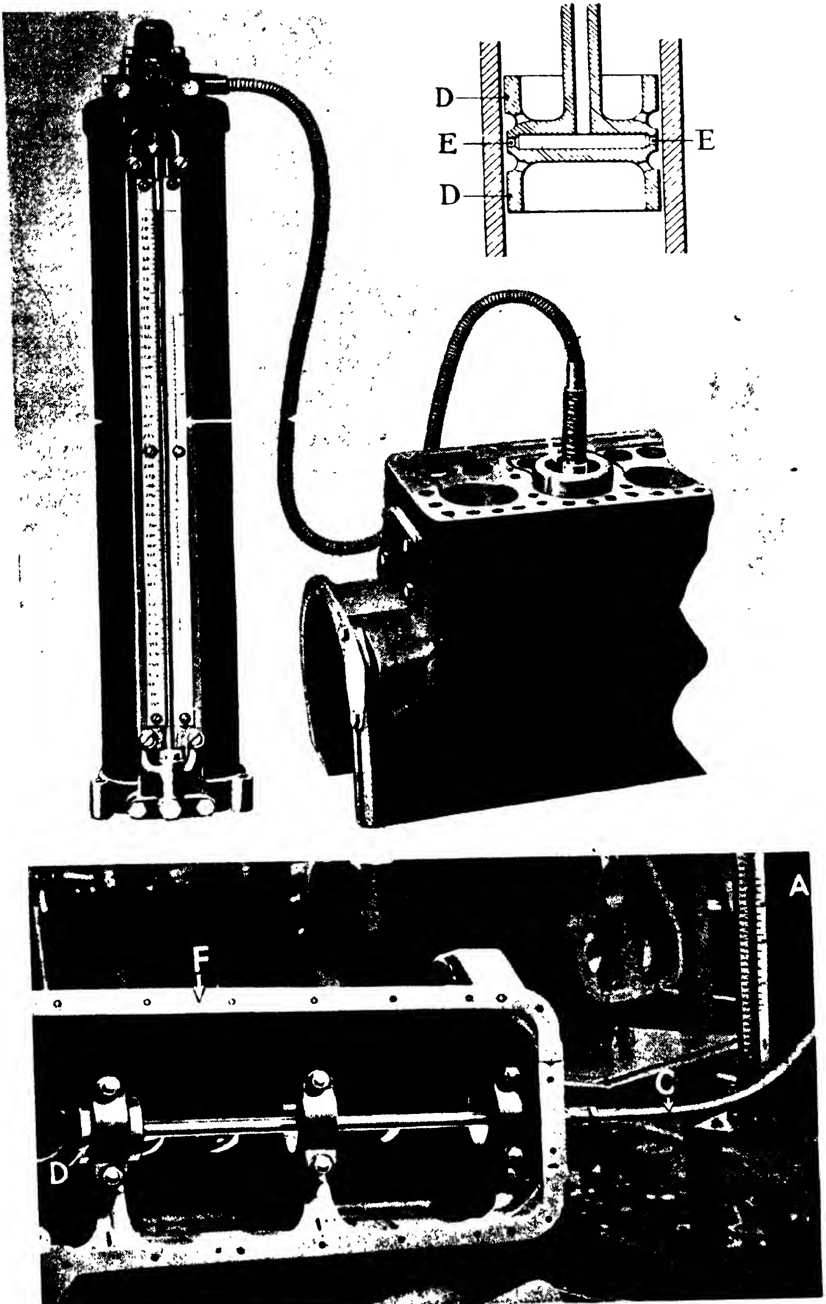
Where parts are given protective coatings the thickness is increased about ·0003 in. in the case of cadmium plating and about ·00125 in. in the case of cosletizing. BSF and BA studs and nuts so treated are sometimes checked to Inspection gauges, prior to treatment, which have been set ·001 in. under the low limit on effective diameter for studs and from ·001 in. to ·002 in. above the high limit on effective diameter for the nuts. These variations from the limits specified in the B.S.I. reports take care of the extra film of metal after the protective treatment.

In a fully equipped Inspection organization there are "Workshop" gauges which are so dimensioned that the work they produce will pass

By courtesy of *Messrs. Alfred Herbert, Ltd.*

PLATE XA. THE ZEISS MICROMETER

Fitted with "needles" for measuring effective diameters of screw threads.



By courtesy of *Messrs. Burton Griffiths & Co.*

PLATE Xb. SOLEX PNEUMATIC MICROMETER

A = Pressure controller.
B = Graduated scale.
C = Air pipe to gauge.
D = Solex plug gauge.
E = Air leak apertures.
F = Crankcase and bearings.

the "Inspection" gauges when checked in the view room. There are also "Master" gauges, which are only used, as required, for reference purposes when the Inspection gauges are suspect or a new gauge has to be put into use.

For checks on gap gauges and length measurements the master normally consists of a set of Johannsen slip gauges, which offer a more accurate means of measurement than a micrometer since there are no screw pitch errors to contend with or other inaccuracies due to moving parts.

Slips are checked for flatness and parallelism on special highly sensitive machines as well as for variations from their nominal sizes, to an accuracy of ·00001 in.

When building up odd sizes a number of slips may be used in combination by "wringing" their plain surfaces together. The method of wringing consists of placing one slip crosswise on another and then twisting them until their edges lie parallel, but on no account should any pressure be applied.

The slightest amount of dust or grease between the slips will prevent them wringing together satisfactorily.

It is a requirement of the Air Navigation Directions that any departures from the type drawings shall be recorded in the form of concessions, and all such concessions must be filed for future reference during supervision by the authorized representative of the Air Ministry.

2. The finish of stressed parts is of first importance, as tool marks, sharp corners, etc., on parts, when subjected to load running, might develop into fatigue cracks owing to concentrations of stress. Sharp corners at the radii of gear teeth, etc., should be carefully radiused off with a fine file. Rough edges and ragged threads should be removed from all parts, as this "swarf" might otherwise do considerable harm if such parts were built into engines. Chatter marks on gudgeon pins and the like can be detected by rubbing the surface with a split phosphor bronze bush, which will cause the high spots to be seen. This fault may be associated with the speed of the grinding wheel feed or lack of rigidity of the machine or fixture.

Finished steel parts must be cleaned, dried, and immediately protected against rust formation. Parts should never be handled. Chemical cleaners require skill in operation on this account. Corrosion of surfaces has been attributed to failure to entirely remove traces of lubricant used on a machine during machining of the part.

3. Many parts have their weight stamped on them, and others the cast and serial number, whilst nearly all parts have their part number and inspector's stamp. The importance of lightly but legibly stamping these items in the positions indicated on the respective drawings is particularly stressed in Inspection Leaflet No. 128 (A.P. 1208).

Acid and electric etching are carried out on certain case-hardened parts and those which would be liable to damage if the marking was stamped or rolled on. In the case of electric etching, care is required to see that the impression from the pencil is not deep enough to produce local burning of the material.

4. Finished heat-treated and case-hardened parts are normally

hardness tested as a routine procedure, Rockwell or Vickers Diamond point machines being employed. The latter is preferable when the impression has to be made on a working surface, as it is smaller than the Rockwell impression, but in either case it is desirable to lightly stone the locality afterwards. When it is possible to check the hardness of a part adjacent to the working surface, this should always be done. When the test is made the part should be adequately supported and the surface to be tested square with the platform. Full particulars of hardness testing machines and their application will be found in Inspection Instruction No. 406 (A.P. 1208).

5. Certain parts which are manufactured for spares may subsequently require additional work on them before they are suitable for building into an engine. Others may be made oversize or undersize on a particular dimension to accommodate a worn mating part which has been rectified. Thus a re-metalled bearing may be left small in the bore to accommodate a ground journal or pin. Oversize connecting rod bushes are often required and oversize piston rings are fitted to cylinders which have been ground in the bores. This matter is, however, dealt with fully in Inspection Leaflet No. 120 (A.P. 1208).

The ground engineer should be familiar with inspection checks peculiar to certain parts, and I will cite some of them.

1. In-line crankshafts are checked on knife edges for static balance, and with a dividing head for accuracy of the angles of the throws. A check is also required for bowing, the crankshaft being supported on "vee" blocks and "clocked" on the journals, and it must be remembered that the errors shown by the maximum and minimum readings on a dial indicator are double the actual errors. Single-throw crankshafts are mounted on knife edges and balanced with a bob weight suspended from the crankpin.

2. Valve springs should be checked for deflection under loads equivalent to the closed and open position of the valve when assembled to the cylinder.

3. Cams would require checking for contour lift and distortion.

4. Ball bearings would be checked for end float if the relative drawings specify a limiting dimension, otherwise end float is not normally considered of vital importance.

5. Connecting rods would be checked for accuracy of centres, parallelism and twist of wrist pin and gudgeon pin bores, and in many cases the weight.

6. Gas and scraper rings are thoroughly inspected before delivery to the engine builders and rings from engines undergoing repair or overhaul should, as far as possible, be tested in a similar manner at the engine builders prior to the reassembly in an engine. The tests normally carried out on a new ring are as follows—

(i) Radial Loading. This is a test of cylinder wall pressure and has a very important bearing on the oil consumption of an engine. It is ascertained by measuring the load required to just close the ring. It is applied diametrically when using the "Brico" machine, and tangentially when the ring is held vertically in a

vice with the gap horizontal, by attaching a load to the end of a thin flexible greasy wire passing around the circumference of the ring.

(ii) CIRCULARITY. Each ring is fitted into a cylinder with a smooth and accurate bore. A strong light is placed behind the ring and any places where contact is not being made with the cylinder wall, permit light to pass and rejects the ring.

(iii) SQUARENESS. Each ring is placed on a surface plate and, if it does not lay flat, is set by hand. The contact or rubbing face is then checked against a vertical member or gauge.

(iv) GAP. The free gap should conform reasonably to drawing requirements in the case of used rings. The nominal gap is checked with the ring fitted squarely in a gauge of nominal dimensions. For new rings the minimum of gap filing should be permitted. When dealing with used rings, which may be ·005 in. or ·010 in. oversize on nominal dimensions, an appropriate ring gauge would be required.

7. Gear wheels are checked on a rolling jig embodying master gears for meshing purposes. The teeth can also be checked by direct measurement with a tooth vernier, or on the more elaborate gear measuring machine.

The airscrew shaft gears and the crankshaft pinion, comprising the reduction gear, are usually run together on a special fixture before assembly on an engine. This preliminary surfacing of the teeth should be carried out in the normal direction of rotation, and parts so dealt with should be grouped in sets.

NOTE. Most of the inspection checks referred to above involve the use of special jigs and equipment. The engine handbooks usually give full information on these matters and should be obtained for reference.

Inspection should be directed to eliminating faulty work as early as possible and thus avoid the cost of the various machining and fitting operations that would be wasted if the part was allowed to go forward undetected. Errors occurring as the result of wear and tear of machinery, worn dies, cutters, and patterns should always be looked for, and action taken to rectify the moment a fault from any of these causes is noted.

The inspection of rectified or repaired parts should be carried out exactly the same as for new parts, except that repair limits would be established by the constructors, and it would be unwise to vary them unless considerable experience had been accumulated by the ground engineer.

Screw Gauges

Threaded work entails the use of sundry gauges to control the various elements within the tolerances laid down by the British Standards Institution.

The elements of a thread include: full diameter, effective diameter, core diameter, pitch and angle. All these factors, except angle, can be maintained within the desired tolerances by the provision of "go"

and "not go" ring and plug gauges. Hitherto the use of ring gauges has been prevalent, but this system is being superseded by the open type caliper gauge. The "Wickman" is a sample of this later development.

Ring gauges cannot adequately control all the elements of a thread, but the "Wickman" type gauge, which is, in effect, two gauges in one, and is provided with two sets of anvils, controls the dimensions of a screw thread in a similar manner to that of a normal gap gauge. The upper set is similar in form to an external chaser, has threads of full form, and is the "go" portion of the gauge, the lower set is restricted to a few truncated threads which, in practice, forms the "not go" portion of the gauge.

The main advantage of this type of gauge is the fact that pitch, angle, and form are taken care of by the full form anvils, and the effective diameter, which is of prime importance, is controlled by the lower set of anvils. It must be borne in mind that male work only can be checked, and this must be applied in a downward direction on the anvil faces.

The screw plug gauges are still retained for checking female screwed work, the full form "go" plug for general form and pitch, the effective "not go" plug for effective diameter, and the core "go" and "not go" plug for the core or root diameter.

To adequately check any work to the drawing tolerance, "go" and "not go" gauges must be used and sensibly applied, and it must be remembered that force in applying the gauges to the work is not permissible.

It will be observed from the B.S.I. Reports that with a nut on maximum dimension and a bolt on minimum dimension a fair amount of slackness will be obtained. There is always a ·002 in. tolerance between maximum bolt and minimum nut on all but B.A. threads.

Work which requires a smaller tolerance can be made to "close fits," the tolerances in this case being half the normal. Such fits are desirable on master rod bolts and nuts, etc.

There is a method of checking the effective diameter of male screw threads in which calibrated ground needles, or wires, of known diameter are used. A wire is placed in the "vee" on each side of the thread, and the diameter over the wires measured with a micrometer. From this dimension the effective diameter can be determined.

The same method can be used to measure serrated shafts and similar parts, but care must be taken to remove burrs or sharp edges from the teeth before fitting the wires.

Needles or wires are selected so that they make contact about half way down the flank of the thread.

The Zeiss micrometer, of which an example is illustrated on Plate X, incorporates this principle, but the usual methods of suspending the wires or using magnetized wires, which are not entirely satisfactory, have been altered to overcome these disadvantages, the wires being mounted so that they can easily be fitted to the anvils of a micrometer.

For medium-size threads the three wires are mounted in two frames carried on the micrometer anvils.

For measuring coarse pitch threads the pair of wires in the frame is backed by a gauge block which makes contact with the micrometer anvil.

The three wires are held loosely in the two frames so that they will adapt themselves in a position in the thread. The wires in a set are of uniform size, are interchangeable, and may be re-ordered individually at any time.

Rapidity in operation is greatly increased because no calculations are necessary. Tables are supplied for each thread standard, giving the diameter of thread, threads per inch, wire diameter and the reading which the micrometer should register. Any deviation from this latter

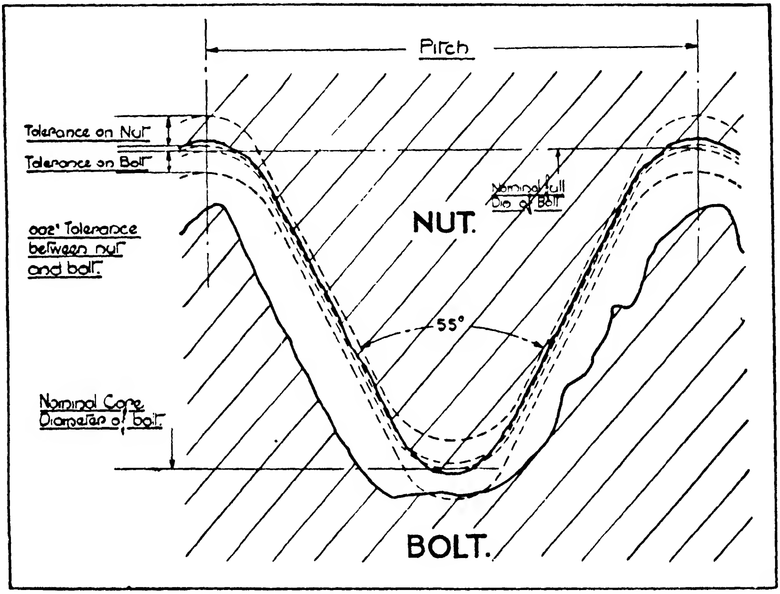


FIG. 5. SCREW-THREAD PROJECTIONS

figure indicates an error either plus or minus in the effective diameter of the thread. Readings can be estimated to the fourth decimal place.

PROJECTION. A convenient method of checking thread forms is to project the magnified profile of the thread on to a screen on which a line diagram of a true thread form is drawn.

Fig. 5 shows such a diagram with the images of bolt and nut threads superimposed on it.

The specimen is set up and the image adjusted to its correct height. If the thread has been properly formed the whole of the image should fall within the two lines representing the permissible tolerance.

In the case of female threads, a plaster impression is made for the purpose of projection.

It will be noticed in the diagram that the thread of the bolt is very rough and incorrect on the crest and effective diameter.

The thread of the nut is fairly good, except for the crest diameter.

One or two manufacturers favour the truncated thread in which the crest is removed. This ensures that a nut and bolt are definitely in engagement on the effective diameter of the threads. In the case of stainless steel parts, the truncated thread reduces the tendency to drag when using the tap or the die.

MAINTENANCE OF INSPECTION EQUIPMENT. The following points give some guidance on this all-important matter—

(1) All equipment should be greased when not in use.

(2) The accuracy of dial indicators is impaired if not handled with every care.

(3) Micrometers should be checked for zero settings at regular intervals by means of the discs and bars supplied.

(4) Setting plugs are required for Wickman gauges, which require frequent checking.

(5) While the Inspector is often held responsible for the accuracy of the normal equipment used, periodical checks should be made of screw gauges and accurate limit gauges, cards being maintained for each gauge. The life of a gauge is assessed by the amount of wear permissible in conjunction with the size and hardness of the surface in contact and the degree of use it gets. After the first check the rate of wear can be determined and the period before the next check established. Specialized equipment is required to maintain accurately the gauges in good order.

Inspection Prior to Overhaul

We now come to inspection prior to the overhaul of an engine, and it should be clear that new or subsequent engines will have been built exactly like the type engine, except that subsequent approved modifications may have been incorporated on later engines. In the same way when overhauling an engine, it is important to maintain a close liaison with the constructors, in order that advantage may be taken of their endeavours to improve the functioning of an engine by the incorporation of any modifications that have been approved. In addition, any modification affecting safety would be promulgated in the form of a Notice to Aircraft Owners and Ground Engineers, and it is a definite duty of the ground engineer to incorporate such modifications, as indicated in the notice, otherwise he would be wrong in certifying a log book on completion of the overhaul.

Notices to Aircraft Owners and Ground Engineers are not issued to a person until he actually holds a licence, although a book embracing all Notices from 1920 to 1938 inclusive may be obtained from H.M. Stationery Office (price 2s. 6d.). All subsequent Notices up to the time of applying for a licence are held by qualified ground engineers, and by consulting them the candidate is able to become familiar with all notices relating to a particular engine.

When an engine is received for repair or overhaul it is advisable carefully to peruse the log book to ascertain the condition and period of running, adjustments, and replacements that were made and forced landings encountered, if any.

It is becoming the usual practice to include as running time only such running as occurs in the air, ignoring ground running, and including ground tests as log entries but not as a part of the period of running between top or complete overhauls.

The engine should be stripped down stage by stage, always using the correct tools, spanners, extractors, etc., provided by the makers for each operation.

Sets of similar parts such as pistons, connecting rods, valve rockers, etc., should have partitioned wooden boxes provided to prevent damage and to ensure that their respective positions on the engine are not lost sight of. The valves could be accommodated on trays which not only facilitate handling but make inspection much simpler.

On some engines, when removing pistons from their connecting rods, it is desirable to slip pieces of rubber tubing over the cylinder holding down studs to prevent damage in the event of any of the connecting rods swinging over.

Do not use corks or wooden plugs to protect oilways and other orifices.

Each part should be carefully examined in the oily condition. By this means the ground engineer can get a good idea as to whether the running during operation in the aircraft has been satisfactory.

Excessive overheating, detonation, etc., in an engine might be evidenced by the condition of the cylinder heads, piston crowns, valve seatings and valves, as also the nature of the carbon on the piston crowns. (See Plates XII and XIII.) This carbon deposit is heat resistive and prevents the dissipation of heat to the crown of the piston, and which would normally be carried away by the oil splashed up from inside the crankcase.

Sand and other foreign matter entering the air intakes cause excessive wear of piston rings, valve guides, valve seatings, bearings and ridging at the top of the cylinder bores. Crankpins and connecting rod bearings may show less distress than the crankshaft journal bearings if the lubricating oil is dirty, owing to the centrifuging effect of the crankpins and reciprocating effect of the connecting rods.

The extent and nature of the sludge in crankpins and oil holes of pistons, etc., and the freedom of rings on the pistons would provide evidence of the suitability of the lubricating oil, under the particular conditions the engine was operating.

Excessive sludging may be due to oxidization of the oil which would produce small amounts of asphaltic substances.

It should be appreciated that oil draining from the underside of pistons may be at temperatures of from 200° C. to 250° C., and this crankcase oil may become oxidized through contact with the exhaust gases that get past badly fitting piston rings. Oils subjected to oxidization may become corrosive and dirty oil is conducive to the wear of parts, heat flow is reduced and carbon is formed. For the above reasons oil should be changed at regular intervals as recommended by the makers of the engine, or earlier if indicated by the condition of the filters.

The residue or sludge in the crankcase filter requires particular

attention so that in the event of metallic particles being found therein the cause can be ascertained as the strip of the engine proceeds.

The oil drawn off from the filter chamber when the filter is removed, should be allowed to settle and subsequently poured away, leaving only the residue remaining. This should be thoroughly washed with petrol several times until all the oil has been removed. The filter should be thoroughly washed and cleaned and the residue added to that already collected. Black particles will give some indication of the extent of carbon formation. If brass or lead bronze particles are present they can normally be identified by their yellow colour. Steel and iron are magnetic and if present would be attracted to a magnetized body. It is more difficult to differentiate between aluminium and white-metal if ether is present, but aluminium will be readily attacked by a 10 per cent solution of caustic soda in water. If there is no reaction, white-metal only can be assumed to be present. As a general statement, metal from main bearings appears as thin flakes or if breaking up badly, small irregular crystals. Metal from bushes which have partially seized will be present in the form of dust.

A further examination of parts would show whether the engine generally had been adequately lubricated, and whether oil ways were clear.

Vibration, both local and general, would almost certainly reflect worrying on the parts concerned.

The next stage will be the cleaning of all parts, followed by a careful and detailed inspection and measure up of all wearing surfaces. The preparation of a detailed report on the work to be carried out is essential.

It is desired to stress the importance of keeping the paraffin washing tanks scrupulously clean, and free from sand and dirt. The paraffin should be periodically filtered and changed. Care should be taken when removing carbon from the various parts to see that no coarse emery cloth is used, as the risk of leaving marks which might be the start of subsequent failure must not be overlooked. Do not use cotton waste for cleaning purposes, as it catches on threaded parts and is liable to get into an engine, if not noticed on assembly. Protect all studs with their own nuts as soon as they have been cleaned, dried, and lubricated.

Inspection During Overhaul

Inspection should be directed to eliminate any parts in which defects have started to develop, or excessive wear is evident which might lead to failure prior to the next overhaul. With established types of engines, performance and other data may be available which would enable discretion to be exercised in the acceptance of parts with minor defects, but as it is the practice to extend the period between overhauls from time to time, this point must not be overlooked. A part might be considered serviceable on a new type of engine with an anticipated life between overhauls of, say, 200 hours, but might be rejected on a well-established engine scheduled to run, say, 400 hours between overhauls.

The constructors of a particular engine usually provide a schedule

of clearances based on long experience of the type. This schedule should indicate the "permissible worn dimensions" and the "permissible worn clearances" of the various parts. The former represent the limit of size to which parts may be worn, and re-fitted for a further period of service, whilst the latter is the limit of working clearances permissible between any two parts assembled together.

It will be realized then that to accommodate this latter condition it may be necessary selectively to assemble parts, that is to say, a part worn near the bottom limit may have to be assembled with a mating part that is closer to its nominal dimension.

The ground engineer should possess a list of clearances for all important parts, and whilst it is unnecessary for him to commit them to memory, he is expected to show an intelligent knowledge of them, particularly where the dimension is critical, such as, for example, the diametral clearance and float of the crankpin bush or bearing shell.

The ground engineer is at liberty to use his discretion in extending these limits, but it would be an unwise course to take unless he had had very exceptional experience of the particular type of engine. Certain operating companies, properly equipped to undertake the complete overhaul and test of their engines, are, however, in this position owing to the accumulated experience of a particular type of engine, but even then a close co-operation is usually maintained with the constructors.

The inspection of parts normally falls into three categories: serviceable, repairable, and scrap. The last one includes parts scrapped for condition, those rendered obsolete as a result of modification or a Notice to Aircraft Owners and Ground Engineers, and parts such as valves, pistons, etc., which are given a limited "life" by some manufacturers, regardless of condition. It is always good practice to mark parts with red paint, adjacent to a defect, so that they cannot be reassembled without rectification.

Split-pins and tab-washers should be soft, and can be annealed by heating to a cherry red if there is any doubt.

Split-pins are never used twice, neither are tab-washers unless they are in good condition and one unused tab still remains. Circlips can often be rendered scrap by overstressing if suitable tweezers are not available, and other methods are resorted to.

Jointing material, rubber and cork packings, etc., very often have to be scrapped owing to condition or prior use. When an engine has been removed from a crashed aircraft all parts must necessarily be under suspicion, and any showing damage or distortion are normally scrapped.

It is important that all scrap is defaced so that it is impossible inadvertently to use it again.

It is now proposed to mention some of the more important points during inspection of the various components prior to rectification and overhaul.

CRANKCASES. A careful examination for cracks in the flanges, stiffening webs, and bearer feet is required, and whilst experience only can decide the seriousness of each crack, it is known that with certain types of engine, cracks in certain places are not unusual, and do not

normally develop, and a certain amount of discretion would be permitted in accepting parts, providing the defects were constantly under observation during routine inspections.

All studs should be checked for tightness, and in cases where a loose stud is found a new one, selected with the thread on the top limit, or, alternatively, a stud ·002 in. oversize, may be fitted. If there is plenty of metal around the stud hole a satisfactory job can be made by bushing the original hole to accommodate a standard stud. The bush should be screwed in tightly and locked by a grub screw.

When broken studs have to be dealt with either on a steel or aluminium part, it is often possible to remove them, without damaging the thread in the part, by drilling, using a drill just smaller than the root diameter of the stud. A carefully applied standard tap will then usually remove the remaining metal threads.

All face joints should be examined for damage and flatness and old jointing material carefully cleaned off.

All oil-ways should be syringed to see that there are no obstructions.

Bearing housings should be examined, and whilst indications of a creeping race will occasionally be found, this is not detrimental providing the bearing is a reasonably tight fit when reassembled. Slackness results in hammering under running conditions with a risk of collapse of the housing, and must be dealt with by fitting an oversize bearing. Care must be taken when machining out the housing to use jigs similar to those used by the constructors, in order that the original centres may be maintained. This point becomes particularly important in the case of reduction gears, where it is essential that the tooth clearances are maintained within drawing requirements.

Many designs of crankcase incorporate detachable steel housings in which the ball or roller race is fitted; in these cases the housing can be renewed and a standard race retained.

CRANKSHAFTS. The first point to check is "bowing." This is done by mounting the crankshaft on "vee" blocks, and checking the bearings with a dial indicator whilst the part is being rotated.

Inline crankshafts should be supported at positions about a quarter and three-quarters along their length to compensate for any sag, and thus eliminate any error due to their weight. Any journals which are clocked should be smooth and true. Crankpins should be checked for parallelism with the axis of the shaft, and all journals and crankpins for ovality and condition.

With modern high-speed engines the maximum wear takes place on the undersides of the crankpins because the inertia forces due to the connecting rods and pistons can be much greater than those due to the explosive effect on alternate strokes. This is particularly so at high speeds and small throttle openings.

In the case of crankshafts of radial and rotary engines, many of which are of the built-up type, it is necessary to make a careful check at the extremities of the shaft when it is mounted on its main bearings supported on "vee" blocks.

If the crankshaft is removed from a crashed engine, or if marks or defects are present which might originate the start of a fatigue crack,

a check should be made by immersing the crankshaft in oil at a temperature of 200° C., drying off the surface oil with a cloth, and then sprinkling chalk over it. As the crankshaft cools down, oil will exude as a fine line on the chalk if a crack is present. Kerosene oil and lamp black is advocated by some instead of oil, while whiting and oil has been substituted for chalk. It has the advantage that it can be painted on and around irregular surfaces. The test becomes more searching if the webs of the crankshaft are hit with a hide hammer. Another method is to etch the shaft, using a solution of 5 per cent nitric acid in methylated spirits. The etching continues until the shaft has become dull grey, when it is washed in a solution of common soda dissolved in water. After the shaft has been allowed to remain for a period of 10 to 15 minutes it should be examined with a 10 : 1 magnifying glass to ascertain whether there is a crack.

The part should be subsequently tempered at from 100 to 200° C. to remove any tendency to brittleness.

Stressed steel parts, as also those with case-hardened surfaces, are normally tested for the presence of cracks with a magnetic crack detector. The principle upon which it operates is as follows—

If a magnetic flux is passed through the steel part to be tested and a crack is present in the flux path, magnetic poles will be formed on each side of the crack.

The part to be tested should be put in various positions, in a fairly strong magnetic field. It should then be immersed in paraffin having soft iron dust in suspension, or alternatively, the liquid may be poured over it. Iron dust will be found to adhere along the edge of a crack, if present, but will give no reaction if the mark is in effect surface damage only. The paraffin should be stirred prior to use.

The part, if serviceable, should be finally demagnetized by passing it through an alternating current field, in order to prevent particles of metal in the oil adhering, when the part is assembled in an engine.

This process will confirm a suspected crack and show up others that might be missed by visual inspection.

The following additional precautions may be mentioned—

(i) Parts must be free of grease, oil, and carbon.

(ii) An aluminium ladle should be used for pouring the paraffin over the parts.

(iii) The test should be repeated if doubt exists as to the presence of a crack.

(iv) A compass will be useful to ensure that parts are demagnetized.

(v) Austenitic steels cannot be checked by this process as they are non-magnetic.

(vi) Cadmium-plated parts must have the plating removed prior to applying the test. Bright drawn bar can also be tested.

The Electra flux test is also made for crack detection. In this test a heavy low voltage alternating current is passed through the part and no demagnetizing is required afterwards. Cracks running in the direction of the current flow are indicated.

A crankshaft should not require re-balancing unless the balance weights are changed. Main bearing housings should be examined for

condition and wear. The inner races of ball and roller bearings are either driven on with the assistance of tallow as a lubricant, or shrunk on to the crankshaft, the latter method comprising pre-heating the race in hot oil. In either case the fit is important, and if it cannot be obtained by selecting a bearing, the crankshaft housing would have to be metal-deposited in an approved manner. Nickel or iron depositions are satisfactory for this purpose. (See Plate XIVA.)

It is undesirable to renew individual rollers of roller races unless the workshop is equipped with suitable apparatus that is capable of measuring to ·0001 in.

The serrations on airscrew shafts should be carefully examined and the hub should be a push fit on the shaft without any appreciable slackness. The cones for the airscrew hubs on other engines should be examined, and any slight degree of picking up eased; the hub should then be lightly lapped on to its shaft, using a fine abrasive.

After thoroughly cleaning the inside taper of hub and the cone on the shaft, the hub should again be offered up to the shaft for correctness of fit. The bore of the hub should be sparingly coated with Prussian Blue, lightly pressed home on the shaft and turned in position. On withdrawing the hub it is essential that it shall show a good marking on the shaft.

When assembling the hub, check must be made to ensure the correct fitting of key which must have top clearance but no side clearance. This can be verified by placing a piece of thin lead wire on top of the key.

To ensure that the hub draws up satisfactorily on the shaft, the taper should be covered with a coating of thin oil, which is then wiped off so as to leave only an oily surface insufficient to interfere with metal to metal contact. Some hubs have a slight difference in taper relative to the shaft. In such cases the hub must not be lapped on to its shaft, as the difference in taper referred to above ensures a tight fit on the rear of the taper which must not be interfered with.

CYLINDERS. Pressure tests, already indicated, would reveal leaky seatings, adaptors, and faulty cylinder head joints in those designs where the barrel is screwed into the head. Such parts could only be rectified by the constructors, who are equipped with suitable apparatus, and even then there is risk of scrapping some of the parts. An adaptor must be carefully fitted so that the flange comes down square on its seating. Similarly the sparking plug adaptor, after being fitted and locked, must be faced in true relation to the axis of the bore. To do this a tight-fitting mandril is inserted in the threaded hole, a hand cutter is then slipped over it to effect the spot facing which is finally checked with a gauge and blue marking. Adaptors should not protrude into the combustion chamber, as isolated threads might easily induce serious detonation. With multiple cylinder head construction, appropriate pressures would be given both to the headers and the water jackets, with a view to revealing cracks, porosity or leaky joints. Suitable expanding rubber joints would be utilized for the tests to block up the various orifices. Water jackets are prone to build up deposits of lime after long periods of engine running, and they can be a source of danger,

from the point of view of overheating, if they are not removed. A 25 per cent solution of Clensol in hot water, circulated around the water jacket for a number of hours, will normally remove the bulk of the deposit. This treatment should be followed by a period of washing with clean water. The nature of the deposit is largely dependent on the source of supply of the water, which may contain salts of magnesium, calcium, sodium, and in some cases iron.

Corrosion of liners may occur on surfaces in contact with the coolant due to electrolytic action consequent upon the formation of batteries composed of two dissimilar metals in the presence of a slightly acid solution. Fibre should be free from chlorides for the same reason. C steel and an alloy steel could form such a battery but Ni and Cr plating are palliatives against corrosive action.

Valve seatings should be examined for tightness, pocketing, pitting, etc., and may be re-cut if the dimensions permit. The practice of fitting N.C.M. steel seatings in cylinder heads of air-cooled engines is now becoming general because of the reduced tendency of the valves to pick up, the superior resistance to leaded fuels, and the greater resistance to shock loadings at elevated temperatures. With seatings in this material, the spring loaded hand-operated tools for recutting the seatings is ineffective, particularly if a cylinder has had considerable service and the seating is scaled. In these cases it is usual to grind the seatings to restore their surfaces, using specially designed power-driven tools such as the Black and Decker, Hall, etc., but care is required to see that the minimum of material is removed in order to get the maximum life out of the part. The equipment includes a fixture, incorporating a diamond, for periodically trimming and dressing the various roughing and finishing grinding wheels. These will probably comprise a set of three or more wheels for each valve seating. It is important that the valve guides have smooth bores within drawing limits as the apparatus is located from them and any errors present would be reproduced. If the valve guide is loose, the hole must be reamed to accommodate a new oversize part but care is required to ensure that forced reaming does not result in cracking the housing if made in Al. It is usual, when the grinding is completed, to bed each valve lightly on to its seating, using a very fine abrasive, finally checking with Prussian blue in the usual way.

In some engines the angle of the seat of the exhaust valve is 1 degree different from that of the seating. It is claimed that when the valve is at working temperature a maximum seat contact is obtained. In these cases bedding the valve on its seating cannot be done, but it is usual to employ a standard angle valve for this purpose. Slight movement of seatings is the forerunner of loose seatings, and a good indication can be obtained by examining the part after careful cleaning. If the seating and head joint is defined by an apparent line, it is advisable to treat the cylinder with suspicion and subject it to a water-pressure test at 400 to 600 lb. per sq. in.

Some engine builders mark the seatings in such a way that movement can readily be detected on examination. One manufacturer, for example, provides three centre pop marks in line, the centre one being

on the cylinder head, whilst the other two are on the adjacent portion of the inlet and exhaust valve seating respectively.

When cracked seatings occur it may be generally assumed that if the material is sound and in the correct condition, the cause of failure is initial overtightening, probably as the result of the use of an incorrect tool permitting too much strain to be imposed.

If engines are permitted to be run with excessive valve clearances, the rebound of the valve on the seating may easily result in abnormal wear and possibly breakage of the valve under the tulip.

Cylinder bores should be checked for ovality at two axes at right angles to each other, both at the top and bottom positions of the piston travel. Cylinder wear is most apparent near the combustion head and the step formed corresponds to the limit of travel of the top gas ring. If this ring has been gummed up for a lengthy period of engine running a second step will make its appearance corresponding to the limit of travel of the second ring. In both cases the positions correspond to the limit of the oil film and the position of greatest heat, producing dry momentary scoring as the oil film is penetrated.

Cylinder wear is normally greater with supercharged engines, owing to the higher temperatures and piston ring pressures. Excessive wear will also result from contamination of the induction air due to sand, etc., and to some extent by the products of combustion.

In starting up an engine the risk of underlubrication is great until oil is splashed up in adequate quantities.

With certain designs of cylinder construction, where the barrel protrudes unsupported for some distance into the crankcase, it may be permissible to extend the limit of ovality at the mouth beyond that established for other positions.

Cylinders would normally be rejected if any blueing was noted in the bores, and would require rectification if any picking up or scoring were indicated. Excessive scoring would entail re-grinding the bore if the dimensions permitted. Re-grinding of air-cooled cylinders will only produce true round bores when the correct equipment is used and there are no soft patches in the metal. The finning in conjunction with thin walls tends to make the grinding wheel cut locally, and glaze in between the fin areas unless every care is taken.

Honing, for which a definition is given in Appendix II, is sometimes done to improve the finish of the bore of a cylinder that has been re-ground, but it is absolutely essential to thoroughly wash out the cylinder in order to remove every trace of abrasive which is used and sludge which is formed during the process. Moderate scoring could be rectified by careful lapping with a dummy piston, using a very mild abrasive, such as Turkey powder made into a thin paste with castor oil, followed by crocus powder (rouge) and oil. For very mild forms of scoring the crocus powder and oil would be suitable.

Inspection of cylinder bores should be done in a good light, and is facilitated by the use of a polished aluminium disc with a rod passing through the centre. This can be used to reflect the light to any part of the bore. Failing this piece of inexpensive apparatus a piece of

white paper placed at the bottom of the cylinder would be of assistance.

VALVES. The power output of modern aero engines has increased, due largely to higher crankshaft speeds and compression ratios. In addition, boosting up to 8 lb./sq. in. is allowed on some engines. Cylinder temperatures, during engine running, have increased, particularly with liquid cooled engines using coolants permitting temperatures well above those possible with water cooling.

Exhaust valves are consequently expected to function at temperatures between 700/900° C., whilst the exhaust gases are over 1000° C. Particular provision is therefore required to carry away the excess heat from the valve heads. One method of effecting the transfer of heat from the head to the stem and thence to the valve guide, is by using a hollow stem valve two-thirds full of metallic sodium. This metal has a melting point of 97° C. and a boiling point of 883° C. It will be seen then, that whilst an engine is running, the sodium will be in liquid form and heat will be transferred by agitation.

The contact of the liquid metal with the wall of the valve stem is better than with other molten salts and the heat transfer is more effective provided the thermal conductivity of the valve guide is satisfactory.

It is known that a valve is liable to develop surface cracks as the result of hardening due to prolonged periods of running at elevated temperatures.

It is probable that gas leakage precedes pitting and burning of the seats, these conditions being accelerated by prolonged running on weak mixtures, or valve stretch causing insufficient clearance which prevents the valve from properly closing. Leaded fuel attacks the heads of valves and stellite or Brightray coatings are provided to retard corrosion. Penetration is less on end grain than along the grain of steel and valve stampings are up-ended and subsequently forged to obtain the former condition on the seats.

The stems are sometimes nitrided in order to reduce any tendency to picking up in their guides and to procure the maximum thermal conductivity.

Exhaust valve failures occur under the tulip, due to intercrystalline corrosion; fatigue resulting, amongst other things, from excessive exhaust gas temperatures.

Prior to actual failure of a valve, circumferential cracks may be noted at a point where the stem blends into the radius of the head, although actually they will occur near or at the region of maximum temperature.

Pitting may also be noted around the stem in the same locality.

Some makers limit the life of valves as a precautionary measure.

For these reasons valves should be examined minutely, after discriminate cleaning, for stretch, cracks on the seats and stems, distorted heads, bent stems, etc.

Fig. 6 shows two gauges which could easily be made and which would prove invaluable in this connection. They include a gauge for checking stretch, and a flat contour gauge. Worn or loose valve

guides can, of course, be replaced by oversize ones, and where fitted, it is necessary to ream them out and possibly re-cut the valve seatings.

It is undesirable to depart from the makers' recommended procedure for the fitting of valve guides, and in this connection it is not usual to use any lubricant as, otherwise, the thermal conductivity is impaired. In other cases it is the normal practice to pre-heat the header before renewing the guide. Valve springs should be examined for surface defects, die-marks and surface erosion. Bent springs and those not sitting squarely on their locations or retaining washers are

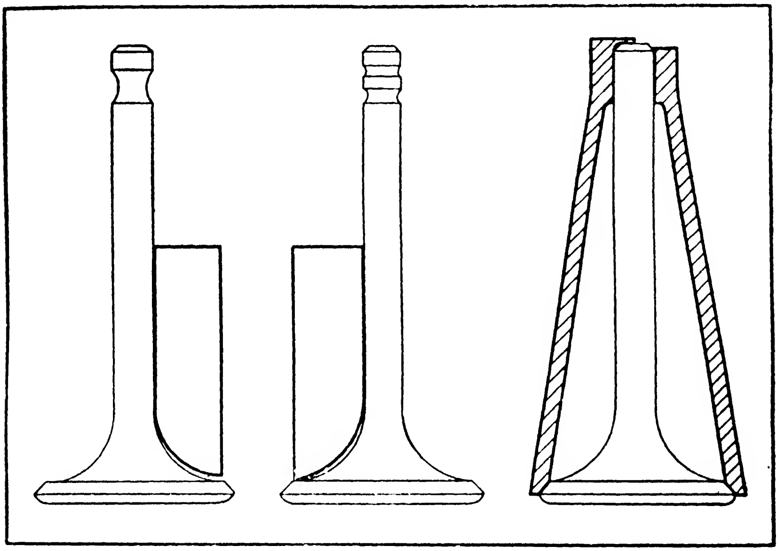


FIG. 6. GAUGES FOR CHECKING VALVE STRETCH AND CONTOURS

liable to fail and will in all probability impose a side load on the valve stem and incur valve guide wear.

Some makers manufacture springs which are only flat when under load. Valve rocker pads, if worn, should normally be renewed, although in certain cases stoning up is possible. Worn ball ends should be scrapped without any attempt at rectification.

CONNECTING RODS. These should be checked in exactly the same way as new parts. Cold setting, to correct any errors of alignment, is not permissible, as this might set up local hardening, and start a fatigue crack at a later date. Particular attention should be directed to cracks around bolt holes, lightening holes, radii, etc. All studs and bolts should be carefully checked for stretching, as the result of initial over-tightening, or deterioration due to hammer loads associated with slack clearances during engine running. Oil pipes and passages should be syringed, and any soldered or brazed joints made good if leakage is noted. Wrist pin and gudgeon pin bores should be carefully checked

for ovality and wear with a suitable plug gauge, having flats on it in such a way that only one axis is operative. A slack bush tends to elongate rather than wear the eye of the rod, and if not dealt with in time, might result in failure. If re-grinding the bores of a rod is permissible, this should be done on a suitable fixture in order to maintain the correct distance between the centres of the bores for the gudgeon pin and wrist pin. On the same kind of fixture a re-metalled connecting rod must have the bearing metal machined to a diameter corresponding to its appropriate pin on the crankshaft, allowance being made, of course, for the initial diametral clearance after bedding the bearing.

There is a growing tendency to fix the bushes in connecting rods, and inspection should be made to ensure that the locking screws, pegs, or dowels are secure. When changing bushes the makers' procedure should be followed, and the interference fit laid down should be maintained.

BEARINGS. It is usual to reject any parts where the white-metal shows the slightest crack or lack of adhesion, and no filling or soldering is permitted under any condition. Cracks develop as the result of shearing stresses set up in the white-metal at points of high pressure, but by discriminate relieving with a scraper the load is distributed over a larger area of the bearing. This slight easing of the metal in the early stages may prevent the subsequent development of cracks. Certain designs of connecting rod are known to be more flexible than others and disintegration of the bearing metal from the shell or rod as the case may be must inevitably occur under running conditions, and cracks will eventually form over part or the whole of the bearing surface, but will not of necessity develop sufficiently before the normal overhaul period is expired to warrant replacement if left undisturbed. Provided the disintegration does not extend to the radiused edges of the bearing, the oil seal is unlikely to be impaired.

To minimize the effects of distortion it is not unusual to provide local reliefs.

If a bearing has been running with a temporary shortage of oil, it has probably been sufficiently warm to wipe the surface of the white-metal. If a slight seizure has occurred oil-holes may be partially blocked with white-metal in addition to very definite evidence of wiping. In the former case rectification might be effected by careful burnishing and the removal of high spots.

When connecting rod bearings are lined with lead bronze, additional precautions are required to those already mentioned, and it may be assumed that the following remarks apply generally to all lead bronze bearings for aero-engines. Uniformity in thickness of the lining must be maintained. This is dependent on the set up for the initial machining. The joint faces of the shells must be smooth and flat so as to retain any nip or interference which may be specified and to reduce any tendency for the bearings to turn. Bearing shells should not be reversed.

When once a new bearing has been properly fitted and adequately run in, a hard glazed surface is obtained, which stands up better to high

loads, speeds, and temperatures than white-metal. The initial surfacing of the bearing can be obtained by prolonged engine running at progressively increasing speeds, or by preliminary running on a rig in conjunction with the discriminate use of dressings. High spots should be removed by scraping as in the case of white-metal. The diametrical clearances are critical and the figures laid down by the manufacturers must be adhered to. If the clearance is on the tight side, there is a tendency to pick up at high speeds with an increase of oil temperature, particularly in the case of the main bearings. If the clearances are excessive, rougher running may be experienced and the oil pump may not be large enough to retain the required pressure in the system.

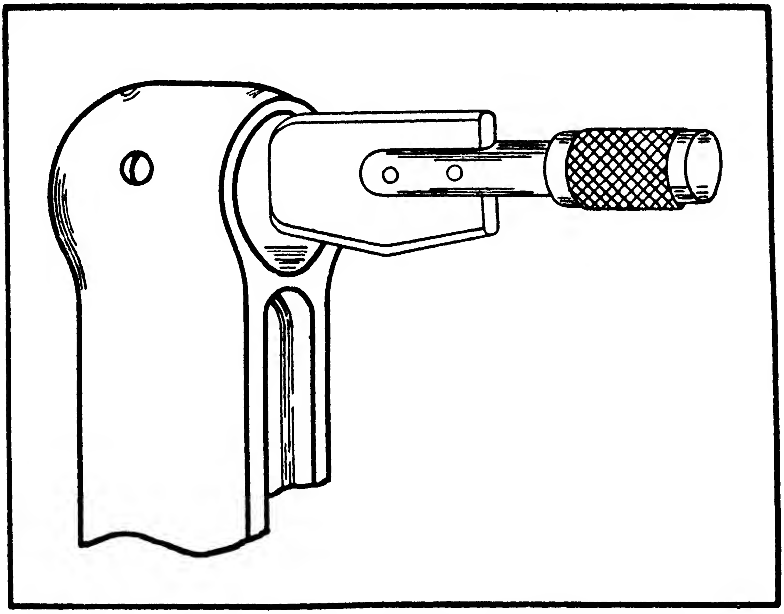


FIG. 7. FLAT GAUGE FOR CHECKING OVALITY OF BORES

The clearances can be checked either by the insertion of a strip of copper foil around the crankpin or by the use of an oversized mandrel.

The Solex pneumatic micrometer is used in the aircraft industry for various classes of precision measurement, that of the bores being perhaps its most general application.

The apparatus consists of—

(i) A pressure controller for air supplied from the mains.

(ii) A column of liquid, with a scale, graduated either in Metric or English measure, on which dimensional variations of the part being measured, are indicated.

(iii) A flexible pipe conveying air to the gauge.

(iv) The gauge.

The height of liquid is a measure of the pressure variation resulting from leakage of air between one or more nozzles incorporated in the gauge and the surface of the bore under-measurement.

A typical male gauge is shown diagramatically in Plate XA and the system is practicable with gauges as small as 5 mm. diameter.

It will be noted that there are two apertures directly opposite to each other. The air leak and consequently pressure variation will occur in direct proportion to the clearance between the apertures and the bore. If the bore is exactly nominal size, the scale reading will indicate zero.

It will be seen that the gauge can be used to explore a bore at any position for ovality, taper and plus or minus errors and 0·0001 in. variation will be indicated by movement of the liquid column of approximately 0·5 in.

The following other applications of this apparatus, for aero engines, are made—

(i) Calibration of small apertures and flows.
(ii) Measurement of journal bearing bores.
(iii) Sealing capacity of valves such as float chamber needle valves.

A certain amount of porosity, as exhibited by pin holes, may be expected but it is not considered to be detrimental. A lead bronze bearing, after a period of running, may show the presence of lead in patches or irregular lines on the surface of the bearing. This is not unusual but must not be confused with wiping associated with oil shortage. If a bearing starts to disintegrate it is usual for the detached pieces to remain in position if the edges of the bearing are intact. Further, it is generally recognized that lead bronze bearings function better with high oil pressure and low oil temperatures.

PISTONS. An examination should be made for cracks, particularly in webs and bosses. Any scoring on the skirt should be rectified by polishing or discriminate burnishing. Any signs of burning should automatically reject the part. The piston ring and circlip grooves should be examined for hammering and wear. Pistons of modern aero-engines are manufactured from heat-treated aluminium alloy forgings, and the effect of prolonged engine running may have an annealing effect resulting in a considerable drop in Brinell hardness on the top lands and crown. Provided that this drop is reasonably uniform on all pistons, it may be considered a normal feature. If pistons are roughly handled, there is every risk of the skirts springing out of round.

Gas and scraper rings should be examined for blowing, loading, and general condition.

It is undesirable to remove piston and scraper rings from pistons unless they are found to be defective or gummed up. If it is necessary, then every care should be exercised to prevent stressing and distortion. A safe procedure is to insert two ¼ in. wide steel strips behind the ring at a position opposite to the gap, then move them apart radially round the piston. Insert a third strip as before and then continue to move the first two strips round until the ends of the ring are free of the groove. The ring should then be moved up the strips until clear of the piston. Each ring should be removed in a like manner. Old hack-saw

blades with teeth ground off can be used in place of strips. (See Plate XI.)

Inspection should be made for "toeing in," feathering, scoring of rubbing surfaces, signs of gas blowing, etc. Any of these defects should normally warrant rejection of the part because rings are cheap. On the other hand, if defective rings are used, the results may be expensive in the long run. A careful check of gaps should be made because ring tension diminishes slightly each time it is heated up, although heat formed rings may behave better in this respect. Rings with excessive gaps, when fitted in the cylinder, may permit hot gases to pass which would in all probability cause local heating of the rings, and if gases can pass behind them this is even more serious. It should be remembered that every ·001 in. rubbed off the surface of a ring increases the gap about three times that amount. On the other hand, if the gaps are too small ring wear will be excessive and feathering with consequent scoring of piston skirt will follow. Tin-plated rings have a less tendency to blowing during running in and reduce wear and risk of feathering.

Ring "flutter" is due to irregular cylinder bores causing the rings to move in and out of the respective piston grooves as they go up and down their cylinder.

Camshafts. The surfaces of cams are normally case-hardened, although in isolated cases nitriding has been substituted. Wear and chipping may be noted on the leading edge of a cam or lobe but this can usually be re-surfaced by careful dressing with a stone. Flaking of the case may necessitate the rejection of the part. Excessive wear can be checked with a contour gauge and rectification by regrinding can in many cases be recommended provided the tracks are rechecked for surface hardness with a Rockwell or Vickers hardness machine, the impression being made at the side of the roller or rocker path. Cam rings as used on radial engines are liable to distort when unbolted from their carriers, while camshafts from in-line engines may exhibit excessive bowing. Some discretion can be exercised in effecting rectification by straightening in certain cases.

Minute grinding cracks may show up on magnetic test, but these are only a few thousandths of an inch deep and do not necessarily follow the direction of the metal flow.

Gears. Fatigue cracks are prone to develop at the roots of teeth as a result of shock loadings during engine running or excessive back lash with a mating gear. They may start from a tool mark produced as the result of poor machinability of some grades of steel or a blunt cutting tool.

Poor finish or absence of radius at the roots of teeth is dangerous and the edges of the teeth should be carefully chamfered.

All gears should be magnetically tested and carefully examined for cracks. The contact faces of the teeth should be examined for "plucking," a condition which is often associated with an insufficient supply of lubricant.

Hardened Parts. All highly stressed hardened parts such as gudgeon and wrist pins will normally be subjected to magnetic test to ensure that they are free of fatigue cracks.

Hollow parts should have smooth bores which should be free of surface defects.

Splined drives must be good fits to obviate hammering and consequent risk of damage to other parts.

Accessories

Under this heading we shall include magnetos, carburettors, oil, air, petrol, and water pumps, compressors, and sparking plugs.

With the exception of magnetos, they should all normally be stripped right down, inspected for wear and mechanical damage, and after re-assembly be subjected to suitable functioning tests apart from those on the engine.

MAGNETOS. These should not be completely dismantled. This work can only be undertaken by a ground engineer holding an "X" licence, a firm approved for magneto overhauls, or the manufacturers.

A number of minor adjustments may, however, be made, and the following details are mentioned for guidance.

If a contact breaker arm is sticking, it may be removed, cleaned, and re-assembled with the recommended lubricant. Contact points should be cleaned, adjusted, and, if necessary, changed. Erratic running may result if they are not given proper attention. Contact breaker springs may be renewed. If the straw-coloured springs show signs of discoloration, due to the action of ozone, etc., this may be taken as an early indication of pending failure, and such springs should be changed.

If the fibre heel on the rocker arm is burnt or worn, it is probable that the cam oil pad has not been regularly lubricated.

It is undesirable to wash contact breakers in petrol, as the burning of platinum points is accelerated if petrol vapour is present.

It is quite permissible to renew carbon brushes after thoroughly cleaning the tracks.

Distributors should be carefully examined for cracks in the moulding, but should not be changed.

Metal screens, lubricators, rusty or damaged external screws, etc., may be changed.

The impulse starter, if fitted, may be dismantled and cleaned.

CARBURETTORS. The inspection of the parts will include—

(i) A careful check of needle valves, throttles, and other moving parts for freedom of movement.

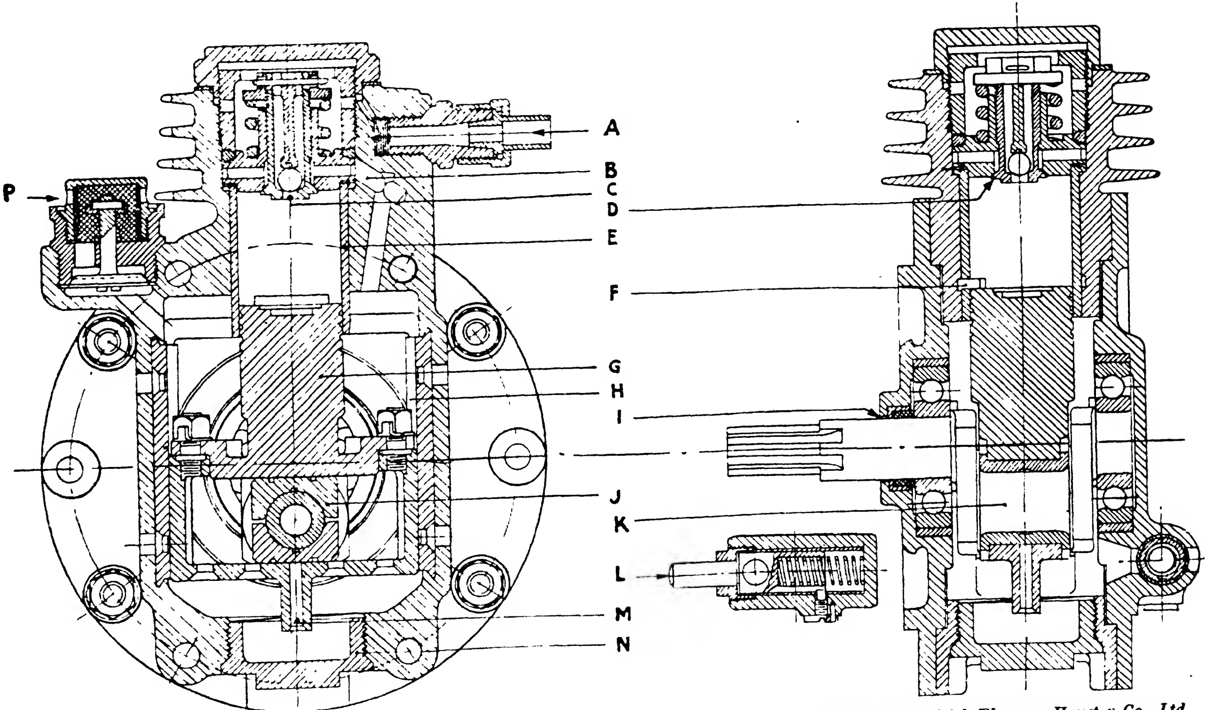
(ii) All pins and toggles must be examined for wear and consequent slackness.

(iii) Floats must be tested for leakage, and cork floats should be specially examined for deterioration of the protective dope coating.

(iv) All studs should be checked for tightness and lugs for cracks.

(v) Butterfly valves may become distorted by engine backfires and should be checked with feelers.

(vi) The mixture control valve seating may be ridged and require rectification.



By courtesy of Messrs. The British Thomson-Houston Co., Ltd.

FIG. 8. B.T.H. AIR COMPRESSOR

A = Air bottle connection.
B = Relief valve by-pass.
C = Ball valve.
D = Relief valve.
E = Cylinder liner.
F = Cylinder port.
G = Piston.
H = Crosshead guide.
I = Oil retainer.
J = Crankpin bearing.
K = Crankpin.
L = Oil level valve.
M = Plunger.
N = Drain plug.
P = Air inlet valve.

(vii) The accelerator pump piston and housing may be scored due to operation when dry.

Prior to re-assembly the joint faces should be checked for high spots and rectified as necessary. Ducts should be thoroughly cleaned and any dope, corrosion, or foreign matter removed. All washers should be renewed and approved jointing only used. On no account may jointing material be allowed to overlap on the inside of a joint.

The calibration of the various components of the carburettor is explained in the chapter on "Engine Build," page 68.

Oil Pumps. These are for the most part of the gear type although plunger and vane types are fitted on some of the early engines. With regard to the gear type of pump, the side clearance of the gears is critical if a good suction-head performance is to be maintained. Diametrical clearance up to ·010 in. and tooth backlash up to ·020 in. are not likely to adversely affect the performance of these pumps, but the makers' figures should be the guide.

On some pumps the gear teeth are backed on the leading side on the driving wheels and on the trailing side of the idler wheels, to relieve pressure due to trapped oil. Similar results can be realized in other ways. For instance, in another design grooves are incorporated at the bottom of the gear chamber.

Fuel Pumps. Diaphragm pumps normally employ fabric diaphragms. The valves fitted are very light and backed by weak springs so that the pumps can operate at any altitude. If large suction lift is required, the valves must not leak. A drain is provided from the chamber behind the diaphragm to carry away any fuel that leaks through the fabric. A gland is provided around the operating mechanism to prevent fuel passing into the engine crankcase.

Dry suction lifts up to 18 ft. can be obtained with these pumps at low speeds if the valves are in good order, but the efficiency decreases if leakage occurs.

Petrol absorbs up to 20 per cent (by volume) of air and has a high vapour pressure. At low pressures, such as those which obtain at altitude or slow running, air tends to come out of solution particularly under agitation produced by pumping. This excess air is given up to the fuel system.

Air vessels are sometimes fitted to trap air passing along the pipes. This also replaces air lost from the vessels as it is liable to be dissolved by the fuel.

An air vessel on the suction side of the pump permits flow of fuel along the pipe line to continue whilst the suction valve is closed and eliminates hammering, in addition to increasing the quantity delivered.

When the air vessel is fitted on the delivery side of the pump, the supply is at a much more uniform pressure.

Diaphragm type of pumps require special attention at complete engine overhauls when the diaphragms should be changed because of the risk of deterioration which may occur to varying degrees, according to the fuel in use and the conditions of operation. When

refitting or renewing a diaphragm it should be in the fully extended position when finally clamped up. The pump should then be subjected to a functioning test on a rig with a 12 ft. suction head, and under conditions similar to those when fitted on the engine.

COMPRESSOR. There is not likely to be much to do to this apart from a thorough cleaning of the unit, and the removal of carbon from the valves.

The makers' instructions as regards the quantity and grade of oil to be replaced should be followed.

SPARKING PLUGS. These should be dismantled, thoroughly cleaned, and re-assembled with the correct gaps. They should then be tested on suitable apparatus to ensure that they function satisfactorily under 100 lb. per sq. in. pressure.

Attention is called to the following points—

(i) Inspection after stripping, should be made for loose mica washers, cracked insulators, bent, loose, or burnt electrodes, damaged copper jointing washers, crossed threads, etc.

(ii) Mica insulators should never be cleaned with an abrasive material and should finally receive a high polish, applied by spinning in a lathe, using a soft felt cloth.

(iii) Never set the gap by bending the electrode because ample adjustment can be obtained by turning the electrode prior to finally tightening the gland nut.

(iv) A plug, prior to insertion in a plug tester, must be quite dry and free of petrol.

(v) A standard jointwasher should be used because if it is too thin, the carbon at the bottom of the last thread may cause the plug to grip unduly, and loosen the insert when removing at a later date.

(vi) Before inserting a plug into the cylinder, smear the threads with a paste of graphite and grease.

Starters

Starting magnetos and motors of electric starters will not be touched by the ground engineer holding a "D" licence, but should be returned to the constructors. The mechanism of an electric starter, apart from the motor will, however, be subjected to inspection for defects in the same way as a hand starter, and on re-assembly the throw-out gear must be carefully adjusted in accordance with makers' instructions. Inertia starters should be returned to the constructors if they are not functioning satisfactorily, as without the necessary equipment for setting the clutch for the particular engine for which the starter is required, unsatisfactory functioning might result.

The principle of the inertia starter is as follows—

Energy, stored up in a flywheel revolving at high speed, is imparted to the crankshaft of the engine to be started.

The "Eclipse" inertia starter provides for the energy to be imparted to the flywheel either by hand or hand and a small electric motor. The starting handle is geared down about 150 : 1 and the energy is imparted from the flywheel to the crankshaft through gearing. A compression spring is incorporated to reduce the shock at the moment of

engagement. When the engine fires, disengagement is automatic, but it can also be effected by hand.

The principle of the gas starter is as follows: A combustible fuel or mixture is supplied under pressure through the gas distributor to each cylinder during its firing stroke.

The cylinders are fed with the mixture in their appropriate firing order. During the ensuing rotation of the crankshaft, the contents of the cylinders are fired by means of a hand-starting magneto which operates through the distributor of one of the magnetos to the sparking plugs. One form of gas starter comprises a bottle of air compressed to about 200 lb. per sq. in., an air pump, atomizer, primer, and accessories, such as pressure gauge, piping, etc. Inspection of these parts should present no difficulty, and the ground engineer should become familiar with the detail, if the engine is equipped with one for starting purposes.

Attention should be paid to the valve units in the cylinders, because weak springs or leaky and distorted valves will result in failure of an engine to start.

Another form of gas starter comprises a complete starter unit, consisting of an air compressor driven by a small two-stroke petrol engine. If this type of starter is used, a knowledge of two-stroke principles will be required, otherwise the overhaul of the unit should present no difficulty to a ground engineer who already holds a "D" licence. A.P. 1181, Vol. II, *Gas Starter Systems for Aero-engines*, obtainable from H.M. Stationery Office, gives full details of these starters.

The Viet gas starter is in general use on the Continent, and, to some extent, in this country. When it is fitted on an aircraft, a Hertzmark or B.T.H. air compressor is fitted on one of the engines to supply the air bottle with air.

The ground engineer holding a "D" licence would normally only be concerned with the compressor and its drive.

The Farman starter, in which a cartridge is exploded in a pistol to provide the initial cylinder pressure to start the engine, is part of the engine, and when fitted would have to be inspected to ensure that it functions satisfactorily.

The Coffman starter supplies the power for engine starting by means of an electrically ignited solid fuel cartridge. The pressure resulting from combustion of the fuel causes a piston to travel down a cylinder. An extension shaft on the forward end of the piston engages a clutch as the piston commences to travel and further movement causes rotation of the drive shaft to the engine through intermediary helical splined pieces.

The operation of the exhaust valve is automatic and the piston returns under load from a spiral coil spring.

A cartridge is used for each engine start and the intensity of combustion can be varied to suit engine conditions by the provision of a range of cartridges.

Engine Build

Re-assembly of the engine will commence after all the rectification has been carried out, and it is very desirable to re-assemble the parts

with plenty of oil, preferably castor, if the engine is to be "run-in" on that oil.

Cleanliness at all stages of engine build is important if scoring of pistons, cylinder walls, and bushes is to be avoided. Assembly should proceed in the order prescribed by the constructors in their various handbooks and instructions, as otherwise trouble may be experienced. As examples of what I mean, it may be stated that in assembling or dismantling cylinders of a certain type of radial engine, damage is likely to be done to piston skirts if for any reason the instructions laying down the order of assembly are not carried out. It is also important that where parts are serially numbered they are fitted in their correct positions. It is quite usual for the following parts to be marked to ensure correct assembly: Master and articulating connecting rods. Bearing shells. Piston, cylinders, valves, valve spring collets. Tappet guides, push rods, camshaft bearings, etc. Mixing of valves, where different materials are used for the inlet and exhaust valves, might result in trouble during engine running, and for this purpose the material specification is usually stamped on each valve.

A thorough knowledge of the oiling system is required to ensure that all oil-ways, passages, grooves, troughs, banjos, and catchers will perform their particular function, and that glands are fitting properly. Crankpin bore sealing caps should be lapped on their seatings to ensure oil-tight joints at running pressures.

All assemblies incorporating oil feeds should, when possible, pass a test with oil under pressure and seepage should be sufficient evidence that the oil passages are open. The position of oil squirts and jets should be checked to see that the oil is directed in the right direction; oil pipe unions and oil plugs should be tested for oil tightness.

The various constructors have, in many cases, established definite procedure, necessitating the use of special jigs and equipment, for carrying out certain of the more important component assemblies, and the ground engineer should familiarize himself with these where applicable. For example, the tightening of connecting rod caps may entail the use of a spring-loaded nut spanner which automatically releases at a pre-determined load. If the split-pin holes do not then line up the nut will have to be faced on the underside. Another example relates to the process of fitting and bedding valve seatings to heads and subsequent cuttering to correct dimensions. A constructor calls for the lapping of the valve spring retainer split collets to the grooves on the valve stem, after which they must be treated as integral parts. Another constructor recommends fitting and removing cylinders only when in a vertical position on the crankcase, and whilst a cylinder is being withdrawn the piston must be kept moving up and down the freely lubricated cylinder. The object of this procedure is to avoid circumferential scores, due to trapped grit, which might otherwise be a source of trouble. A built-up crankshaft may depend, for the security of its maneton, on the tightness of a bolt passing through the split end of the web. This is checked by the amount of stretch resulting from the tightening and it is well to remember that loads imposed on bolts or

studs, greater than the elastic limit of the material, must result in permanent stretch and subsequent failure of the part

Roller bearings should receive special attention during assembly into an engine, and it will be found that in many cases the rollers can be held in position on the inner race by means of an elastic band whilst the outer race is being assembled. Failures associated with roller bearings, apart from those attributable purely to normal wear and tear, are usually due to one of the following—

(i) Lack of lubrication.
(ii) Incorrect clearance.
(iii) Malalignment.

The following points should be remembered in connection with each of these headings.

(i) Every care should be taken to see that oil feed holes, passages and grooves to the bearing, are quite clear and that the parts are assembled with plenty of oil. If the oil film between the rollers and one of the tracks is destroyed, disintegration of the hardened surface of the race must soon occur.

(ii) Lack of roller clearance in a bearing will produce a tendency for individual rollers to bind, resulting in the load being localized with consequent damage to roller and track. This condition might be accentuated or relieved as the part becomes hot. Close adherence to the makers' recommended clearances and methods of checking same is necessary to ensure satisfactory functioning.

(iii) Malalignment may occur as a result of one or other of the races being eccentric due to the housing being distorted or worn. Again the inner race may be slack on its shaft, or the locating shoulder may be out of square or may have received damage which prevents the race being driven home. The nut which holds the race in position may be slack, and it must be remembered that this nut may be right-hand or left-hand, according to the direction of rotation of the shaft.

With the recent introduction of needle roller bearings it may be of general interest to mention a few points relating to their use.

The main advantage of these bearings are—

(i) They can be accommodated where space makes larger rollers unsuitable.

(ii) The long roller provides a greater length of contact for carrying the load, thus allowing a considerable reduction in diameter.

There is a greater tendency for long rollers to "skew" when running, and accuracy in manufacture becomes all important. The bearings are more suitable for reverse loads such as those occurring when used as bearings for rockers, push rod ends, etc.

Diametric slackness is essential, particularly for high speeds, with the result that the rollers rotate on their own axes only when under load, and slide without rotation when free. Bearings must not be fitted up with rollers crowded together so that no play is left. End slackness is equally important and provision must be made to adequately lubricate all moving parts.

The back lash of the trains of gears to the camshafts, magnetos, and accessory drives must be checked, using the methods and apparatus

indicated by the engine manufacturers. The back lash of important gears should be checked at a number of positions, care being taken that no dirt is present on any of the teeth.

It is important that checks of assemblies are made and important clearances duly recorded at all stages of erection. The centralization of the crankshaft requires every care so that it is correctly located in the crankcase. Similarly, in the case of certain inline engines, the bedding of the crankshaft on its bearings in the crankcase will have to be checked with mandrils, as used by the constructors. Care must be taken that the appropriate nip of the bearing cap is provided, and when roller bearings are concerned that the required roller clearance is not absorbed.

Particular attention should be paid to the clearance and end float of all white-metal, cadmium and lead bronze lined journal and connecting rod bearings, and also the method of checking and obtaining these clearances, both from the point of view of the life of the bearings, and the oil consumption of the engine. It is not unusual to bed connecting rods with bearings fitted to oversize mandrels to obtain these results.

The question of tightening of nuts is dealt with in Inspection Leaflet No. 132 (A.P. 1208), and it is desired to stress the importance of using only those spanners designed for a particular nut, component or purpose, as otherwise parts may be stretched, distorted, or damaged. Stainless steel B.S.F. and B.A. studs and nuts are liable to seize unless free engagement is provided by selective assembly.

A liberal supply of oil should be used when tightening large nuts with tab washer locking, in order to reduce the risk of shearing a tab, if the nut suddenly bites into or grips the washer.

The importance of carefully split-pinning the main components, such as connecting rod bolts, is a matter which cannot be too fully stressed. The tendency is to provide reamed holes and to select pins that give a slight interference fit, that is to say, they may require a gentle tap to make them enter. The split-pin is entered so that the head fits snugly into the slot of the nut. One leg is bent over the top of the bolt, and the other down the side of the nut. Sometimes it becomes necessary, when a leg cannot be bent over the top of the bolt, to use a split pin which has been twisted through 90°. The twist is made while the ends of the legs are held in lead jaws in a vice. After assembly, the legs must be bent round the nut. They must not be hammered as the edges of the castellations are very sharp.

It is not unusual to use soft split pins for the initial build of an engine, substituting stainless steel ones on final erection. In cases of mixing, the soft pins turn brown when immersed in $CuSO_4$.

In the event of a nut or split pin (if magnetic) falling into a partly assembled component it can usually be retrieved by means of a magnet suspended on a piece of string.

Grover and spring washers, when used on bolts securing joint faces under pressure, do not prevent seepage of oil past the stems of the bolts. A close-fitting washer must be used as well.

The elastic limit of piston ring material in conjunction with the design should permit a ring to be opened sufficiently for fitting on to a

piston without causing any permanent set or distortion, provided normal precautions are taken. Distortion might have detrimental effects on the oil consumption of an engine due to the destruction of the oil film. In the same way an increase in permanent set would raise the cylinder wall pressure, which might reduce the oil film to such an extent that excessive wear resulted. It will be seen that the fitting of a ring to a piston is important and the procedure for removing rings should be employed when refitting them.

If cylinders have been ground oversize, rings should be obtained which are a similar amount larger on nominal dimension. Normally oversize rings are available in steps of ·005 in. Piston rings which permit exhaust gases to pass will encourage cylinder wear because of the destruction of the oil film. The seal is assisted in the case of the top gas ring by gas pressure acting behind the ring. This is dependent on the efficiency of the seal between the side face of the ring and the groove in the piston, which must be perfectly flat. For this reason piston rings are sometimes ground and lapped on their side faces. The piston material must be sufficiently resistant at elevated temperatures to maintain a flat groove for the side face of the piston ring to bed on to.

Gas rings with 1° chamfer from the middle of the contact face are sometimes used and it should be realized that this chamfer has the effect of doubling the loading per square inch on the cylinder wall. Such rings will bed in quickly, although wear will take place much more rapidly if lubrication is inadequate. Care should be taken to see that piston and scraper rings are fitted and disposed around the engine in the manner, as regards gaps, chamfers, loadings, etc., specified by the makers. Excessive piston clearances permit rings to wear oval with resultant loss of efficiency as regards maintaining the oil film. For this reason some engine builders stock oversize pistons.

Cylinder distortion will impair the effectiveness of gas tightness of a piston ring in spite of pressure loading behind the ring. Furthermore, a high-class cylinder bore finish is of no avail if distortion due to mechanical effort is permitted. For these reasons the engine-makers' instructions for tightening the bolts securing detachable cylinder heads must be followed. It is equally important in the case of monoblock constructions if water and oil leaks and even cracking of the blocks are to be avoided.

When fitting cylinders to split crankcases of radial engines, careful scraping of the crankcase spigots must be made, and when the two halves of the crankcase are subsequently tightened up with the cylinders assembled, "go" and "not go" plug gauges must be tried in the cylinder bores to safeguard against excessive "nip" and resultant ovality. In the same way where cylinders are secured by locking rings, as in the case of the Siddeley range of engines, the makers' instructions must be carefully followed. The ring should be gently tapped all round with a hide hammer as the locking screw is tightened, and only the standard spanner should be used.

Overtightening may distort the barrel, and undertightening may enable the cylinder to become slack on subsequent running.

Several types of poultice head cylinder construction may be

encountered, which require removal of studs and careful scraping of surfaces if heads or headers have to be changed. In these cases the makers' handbook instructions should be followed.

The compression ratio of an engine is established on the Type Engine, and must not be exceeded on subsequent engines, except in the case of normal rectification of surfaces during overhaul which will tend slightly to raise the compression ratios, but within permissible limits.

An increase of compression ratio will give an increase of power which might overstress the parts. There is also a risk of detonation occurring.

It is possible to increase the compression ratio by reducing the clearance volume on different types of engines as follows—

(*a*) By fitting higher compression pistons.

(*b*) Where cylinder heads are normally detachable from the barrels, by fitting heads with decreased combustion space.

(*c*) By removal of packing ring, sometimes fitted under the holding down flange of the cylinder.

(*d*) Where cylinders are screwed into the crankcase or separate adaptor rings, by screwing the cylinders further into their location.

It is advisable therefore occasionally to check the compression ratio of engines, which is done as follows for each of the conditions cited above.

(*a*) Check weight and part number of piston, also height from axis of gudgeon pin to crown.

(*b*) Effect a volumetric check of the combustion space of the head with thin oil. To do this the head is inverted and set up with the joint face horizontal.

(*c*) This can be checked visually, it being only necessary to measure the thickness of the ring, if fitted.

(*d*) Cylinders of rotary engines are checked from centre of rocker standards to crankcase, with a height gauge. In another case the height is controlled by the cylinder locking ring gap.

With regard to check (*b*), it is desirable to ascertain the true cylinder capacity from time to time and the following information is supplied for this purpose.

Determination of Compression Ratio by Direct Measurement

(*a*) Fill the space in the cylinder with a suitable medium and then measure the quantity used. This operation is carried out with the piston at the top and bottom positions in the cylinder respectively. The medium recommended is a thin mineral oil. It should be noted that paraffin is unsuitable, and liable to give false readings owing to leakage which might take place.

(*b*) The test should include at least one cylinder on each bank in the case of "V" type engines, and the cylinders with the minimum and maximum stroke variation, and one with a master rod in the case of radial engines. At least two cylinders should be tested on "in line" engines.

(*c*) In carrying out the test the valves will be fitted in the closed position, and this may necessitate the removal of part of the valve

gear. Orifices will be closed with their respective components except one sparking plug hole through which the medium is entered.

The standard piston with its rings will be assembled in the engine, the rings having previously been lubricated with thick tallow to prevent leakage of oil.

(*d*) Before pouring in the oil, the engine should be tilted until the sparking plug hole face is, as far as possible, horizontal. This will be facilitated if the engine is mounted on a tilting stand.

Oil is then poured into the cylinder from a graduated measuring glass, care being taken to avoid formation of bubbles as the cylinder becomes nearly full. The engine should be rocked in order to release any trapped air.

(*e*) It is usual to deduct about 1 per cent from the measured quantity of oil to allow for some clinging to the measuring vessel.

(*f*) The compression ratio will be arrived at as follows—

$$\text{Compression ratio} = \frac{\text{the swept volume} + \text{clearance volume}}{\text{clearance volume}}$$

As the assembly of an engine nears completion the various accessories such as magnetos, carburettors, oil pumps, etc., will be assembled. Oil pumps and small auxiliary oil pumps should have been run on a rig at speeds and under conditions as regards pressures and temperatures similar to those when functioning normally on the engine.

If magnetos have been overhauled either by a ground engineer holding an "X" licence, or the manufacturers, suitable functioning tests would already have been carried out.

Care is required in fitting magnetos to the engine to ensure that they are properly aligned, if of the platform type, otherwise the laminated spring drive will certainly give trouble.

If they are spigot mounted the gear wheel clearances are important.

Magnetos should be timed fully advanced with contact breaker points set to break with the correct gap. Normally the timing can be set to within $\pm \frac{1}{2}°$, and magnetos can be synchronized to the same limits. If the points are set too far apart the timing will be advanced and the spark intensity will be impaired if the break does not occur in the most efficient position of the armature in relation to the magnetic field.

A variation in gap of ·001 in. may alter the timing as much as $\frac{1}{2}°$. A worn contact breaker arm heel will retard the timing.

There are several methods of setting the ignition timing on an aero-engine. When I say ignition timing I mean the position of the piston in No. 1 cylinder on the firing or compression stroke, or alternatively the angular position of the crankpin, at the moment the actual separation of the contact breaker points occurs.

One of the simplest methods is to remove the contact breaker cover and observe the break, or separation, of the points as the engine is turned slowly forward. This should be repeated several times, and the position of the piston in the cylinder, or the angularity of the crankpin, checked each time. The former is done by inserting a suitable gauge into one of the sparking plug holes, an arm incorporated in the gauge making contact with the crown of the piston. The angularity of

the crankpin is ascertained by means of a graduated timing disc which can be attached to the airscrew shaft, or other suitable place. Certain manufacturers dispose of the timing disc altogether, the correct position for ignition setting being indicated on the periphery of the annulus wheel in the case of some geared engines.

A method of checking the ignition timing consists of inserting a strip of cigarette paper between the contact points, and noting just where it is possible to pull the paper out. This will correspond to a gap between the points of approximately ·0015 in., but should not involve any appreciable error in the timing. A ·0015 in. feeler blade would be a suitable alternative to the paper.

There is an electrical method which requires the use of an ordinary flash lamp battery, a small lamp, or alternatively a bell. The circuit is made by connecting a lead from the insulated side of the contact breaker to a terminal of the battery. The lamp is then connected in series with the other terminal of the battery, and finally a lead from the lamp to the earth side of the magneto or engine.

On all rotating armature type magnetos, and those having an external primary lead, the lamp should light when the points make contact, and becomes extinguished when the points open. On other types of magnetos the light should become dull instead of extinguished when the points open. This is due to the fact that magnetos having a permanently fixed primary lead to the contact breaker offer an alternative electrical circuit when carrying out this test. It must be noted in this connection that on rotating armature type magnetos the centre or earthing screw must be removed before this test is commenced.

Tests of carburettors vary according to the type, but a number are general for all carburettors, and the most important of them will be mentioned.

1. A flow test is made to ensure that a supply of fuel is available at the jets, well in excess of the full throttle consumption of the engine. The test is made at the minimum fuel head at which the carburettor is expected to function, the plug under the jets is removed, and fuel is run through from the float chamber and collected in a measuring vessel.

2. A flooding test is imposed on the needle valve in the float chamber. This is done by supplying fuel at a pressure equal to the maximum head for a certain time, during which no flooding should occur, even though the carburettor is tilted 15° in all directions.

3. The level of the fuel in the float chamber is checked and adjusted if necessary.

4. The mixture control valve requires an air leak test, normally about 1 lb. per sq. in., during which no leakage should occur.

5. The jets are calibrated on approved apparatus to ensure that the correct petrol flow, in cubic centimetres per minute, is obtained.

6. The range of mixture control on vacuum type carburettors is checked by testing the carburettor complete with its elbow and air intake on a blower plant, providing an artificial depression equivalent to that obtained when the carburettor is functioning on an engine at full throttle and normal r.p.m. The specific fuel consumption with the

PLATE XI. A GOOD METHOD OF REMOVING AND FITTING PISTON RINGS

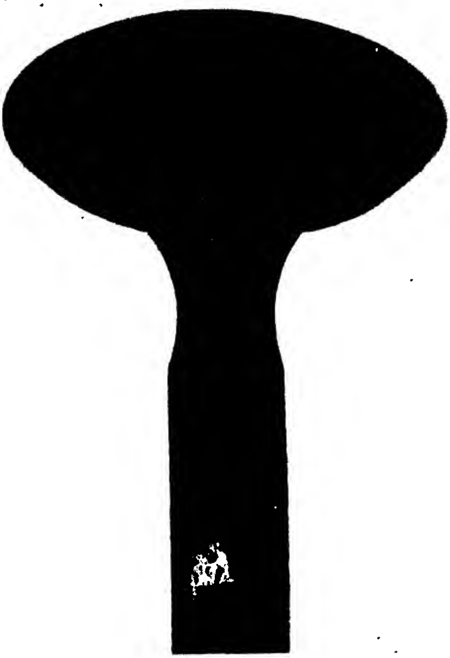


Plate XII. Scaling and Corrosion Due to Excessive Temperatures

Plate XIII. Sunk Piston Crown Resulting from Excessive Temperatures

Due to very weak mixtures, detonation, etc.

mixture control open and closed is then read direct from the flowmeter. A check can also be made with the carburettor fitted to the engine if the mixture control range does not exceed, say, 15 or 20 per cent. Erratic running of the engine may be anticipated with the mixture control full open, when a larger percentage of control is provided, and in these cases it is possible to enrich the mixture for the test, either by increasing the size of the main jet, or by a constant auxiliary supply of petrol direct into the induction pipe or air intake.

7. With those carburettors incorporating heater jackets it is necessary to check the cover joints to see that they are properly made, by subjecting the system to a pressure at least 50 per cent in excess of the normal pressure under engine running conditions.

8. If an accelerator pump is fitted its correct functioning should be checked by a number of quick accelerations, the displacement of petrol being measured at the same time.

9. If the butterflies and spindles are oil heated, a pressure test with hot oil is required to test glands and joints.

10. Some modern carburettors are rendered automatic by the provision of exhausted capsules to control the enrichment and altitude jets respectively. The settings must always be carried out in accordance with the maker's instructions. Mixture control, providing full strong and full weak positions only, is sometimes incorporated.

The capsules must respond to definite deflections according to changes in temperature, barometric pressure in the case of the altitude capsule and boost pressure in the case of the enrichment capsule.

On overhaul, capsules should be checked for leakage or damage and to ensure that the required rate of deflection has not altered.

Engine Tuning

Re-assembled engines must be submitted to bench tests to prove out any new parts that have been fitted, and to show up any faults of assembly, but prior to these tests, running in and "tuning" are of first importance, particularly if new major parts have been fitted. Starting up an engine from cold requires special mention. Correct priming to ensure satisfactory starting is a matter of experience, and over-priming with fuel must be avoided as it may result in the oil film on the cylinder walls being destroyed. Excessive flooding of the float when down-draught carburettors are fitted is equally undesirable for the same reason. Cold starting, particularly with wet fuel, is very conducive to cylinder wear and chemical action resulting from condensation must also be reckoned with.

Abrasion of cylinder walls can be avoided by ensuring that only clean air is admitted to the cylinder. Excessive oil temperatures will tend to score pistons due to oxidation and formation of carbon.

If at any time during the preliminary running-in of new parts the surfaces become dry, it is almost certain that scoring will result, and in the case of cylinder bores the scoring may be serious, and similar scoring is likely to be indicated on the piston rings and pistons also. It may be so serious that normal methods of rectification will not restore the original condition. If, however, the parts behave satisfactorily

during the running-in and endurance tests, it is probable that a surface will have been formed which will improve on subsequent running.

In order to safeguard against the possibility of cylinder dryness occurring, some people favour upper cylinder lubrication, that is to say, whenever it is necessary to open the throttle after starting up an engine, a quantity of lubricating oil is sprayed into the air intake at the same time, and possibly at intervals during the running-in period. Colloidal graphite, such as "Oildag," added to the lubricant is used by some manufacturers and it is claimed that initial cylinder wear is reduced and the walls are quickly surfaced.

Oils are also processed by the addition of proprietary dopes so that higher loadings can be employed.

Running-in and tuning an engine with castor oil is preferable to mineral oil, and much improved surfaces of piston rings, piston skirts, cylinder bores, etc., will result. The constructor's instructions regarding an initial supply of lubricant to certain parts of an engine, prior to starting up, should always be observed, and with certain engines the valves of the bottom cylinders should be raised slightly to permit any accumulated oil in the cylinder and induction pipes to be released.

An accumulation of oil in the lower induction pipes may occur through drainage from other parts of the induction system, and from the combustion chamber as a result of crankcase oil passing through the oil holes in the gas ring grooves of the piston, on shutting down after a previous run. It is possible to turn some engines by hand without displacing the oil in the induction pipe, but a sudden suction resulting from the initial firing in one of the cylinders, might carry the oil through and damage the cylinder. Where induction pipes incorporate drain plugs, they should be removed prior to a run, and when refitted securely locked again.

Serious trouble may also result if petrol or water are trapped in the combustion chamber. The former could occur through a leaky priming system, and the latter by a faulty header or leaking cylinder liner joint.

With engines fitted with lead bronze bearings, it is undesirable to turn the crankshaft if they are not adequately lubricated. Hot oil at normal running pressure, should be pumped into the system for from 5 to 10 minutes to ensure that the bearings are adequately lubricated. An engine should only be started up when it has been ascertained that the parts are adequately supplied with oil, and should be run initially at a speed just sufficiently high to ensure that parts such as cylinder walls, etc., relying on splash and oil mist, are adequately lubricated. The speed and load should be progressively increased as recommended by the makers. Observation should be made throughout this period of running for water leaks from jackets, oil leaks at unions and joints, etc., general and local over-heating, vibration, detonation, slow running, acceleration, etc. Oil seepage may be noted if there are any porous patches in walls of Al castings, and peening over should only be permitted with the prior consent of the chief inspector.

Vibration may be associated with mal-alignment of the engine on the brake, quite apart from causes due to faulty ignition or carburation, dealt with under Section "Location of Faults,"

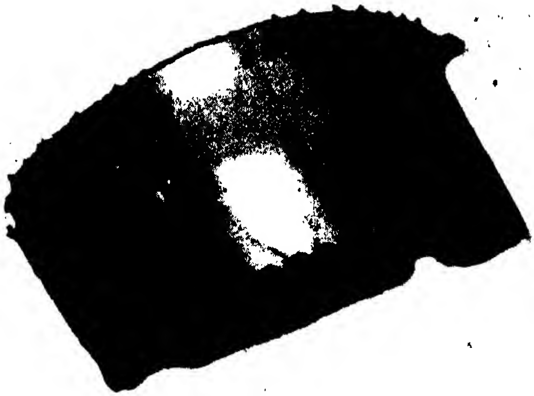


PLATE XIVA. FILM OF ELECTRICALLY-DEPOSITED METAL, WHICH BECAME DETACHED DURING THE SUBSEQUENT GRINDING OPERATION

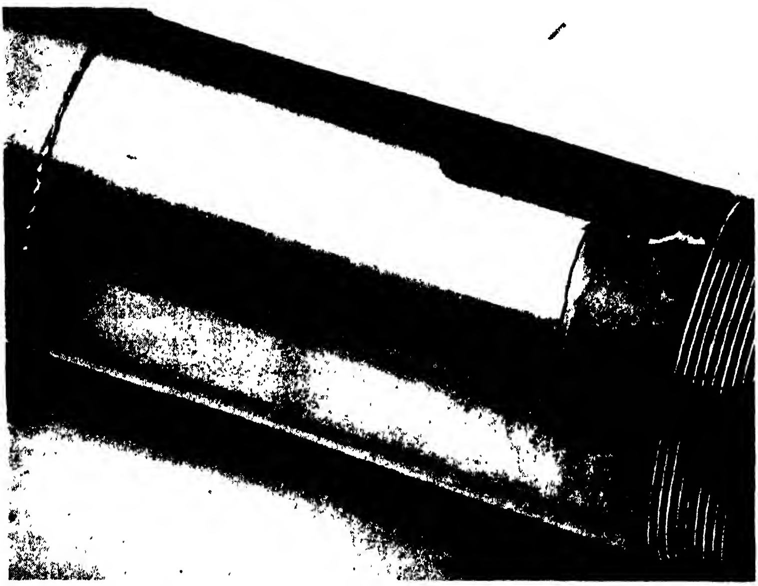


PLATE XIVB. THE SHAFT, SHOWING WHERE THE FILM OF METAL BECAME DETACHED

Detonation may be suspected if puffs of smoke are noted in the exhaust flames, but a more searching check can be made with the Farnborough indicator, but as this is not normally part of the workshop equipment it becomes necessary to adopt an "audible" check; here again, however, to get any degree of reliability the engine exhaust should be properly silenced, but with practice it is possible to determine, within 50 r.p.m. the speed at which detonation commences.

The engine should be run at full throttle or M.P.B., and the observer should be as near as practicable to the cylinders, taking note of intermittent and regular detonations.

The effect of exhaust manifolds may easily advance the detonation period by 100 r.p.m., whilst flame traps, if fitted, tend to mask the extent of detonation.

The initial pressure after the first part of the charge has ignited may be as high as 450 lb. per sq. in., and the resultant momentary pressure when the "pink" takes place may be several times as great.

The danger from detonation is excessive overheating followed by burning, and sometimes caving, of the piston crown, burnt sparking plugs and exhaust valves.

If an engine runs a power curve with standard fuel and a repeat power curve with doped fuel, the two curves should be of similar character if detonation is absent. A high octane fuel does not of necessity give improved fuel consumption; it does, however, permit higher cruising power on weak mixtures and higher take-off power with less risk of detonation.

The use of a fuel inferior to that specified for a particular engine may induce detonation.

Slow Running. This test should be carried out without any artificial heating to the air entering the carburettor, and whilst it may be done with the airscrew fitted, the inertia will be far greater than that of the fly-wheel and coupling on the test bench.

The valve clearances should be accurate before the test is made, and the sparking plugs must be clean.

Valve clearances should be checked as indicated by the makers. Unreliable results will be obtained by shutting the engine down, and then checking clearances hot, particularly with austenitic valves. It is known that on some engines fitted with these valves, the expansion is very great, and the sudden cooling of the valves on shutting the engine down may result in the clearances actually increasing, it being a matter of minutes before the other parts have cooled sufficiently to effect a correct compensation.

Failure to secure satisfactory slow running has also been traced to leaking glands, fitted on the fan spindles of certain supercharged engines.

Acceleration. The carburettor should be tuned to give satisfactory slow running at about 80 per cent below normal r.p.m., and the engine should respond to snatch openings of the throttle both at economic normal and rich settings.

Faulty accelerations are much more likely to occur when opening up from slow running than from take-off speeds and above.

Oil System. With regard to the oiling system it is usual, where an auxiliary crankcase feed forms part of the system, to calibrate this fitting when the oil pump is tested on the rig, and under normal operating conditions as regards pressure and temperature. High oil pressures usually result in high oil consumptions, and a relief valve should be adjusted to show a pressure near the bottom of the rating. In the same way engines should be passed off test with oil consumptions as near to the bottom of the rated figures as possible. High oil consumption may be due to leaky oil pipe unions, tappet guides and breathers, excessive clearances of bearings, leakage past the gas rings, etc. The latter can be located on one or more cylinders if the engine is fitted with separate stub pipes. The use of a lubricating oil for testing engines inferior to that used on the type engine is not permitted.

Induction Systems. These will have already been subjected to a smoke test to ensure that all joints on the system are properly made. This necessitates the removal of push rods on radial engines to ensure that all valves are seating. Alternatively, valves are often tested by pouring paraffin behind the seatings and applying air pressure at 10 lb. per sq. in. when excessive leakage would necessitate re-grinding the leaky valves on their seatings.

The smoke test is carried out by placing a piece of smouldering rag into a box fitted on to the induction elbow. Air is supplied to the box from a hand pump, or air pressure supply, and the smoke is forced through all the passages of the induction system.

The carburettor will have already been proved to function satisfactorily on the blower plant, but a check on the engine will show if there are any flat spots or irregular running. The flowmeter reading is a good check of the correctness of the carburation, but a further check can be made by running the engine at nine-tenths of full throttle in subdued light with stub pipes fitted, and noting the exhaust flame colours, and whilst they may appear to vary slightly with each type of engine, according to the distribution, the generally recognized symptoms are as follows—

Very rich mixture.	Smoky and long irregular blue flames.
A rich mixture .	Long narrow blue flames.
Normal mixture .	Short bluish Bunsen type of flame.
Weak mixture .	The blue flame of the normal mixture changes to a narrow transparent dull green.
Very weak mixture	An almost transparent flame with a red centre and possibly intermittent "popping back" in the carburettor.

The red coloration does not give any indication of the correctness of the distribution, and is largely associated with the lubricating oil.

The black smoke with the very rich mixture cannot, of course, be noticed if the test house is quite dark.

If a smoky exhaust is obtained during slow running this is an indication that the slow running jet requires adjustment.

Weak mixtures cause high peak temperatures around the combustion chamber surface, due to the slow and incomplete burning of the fuel.

The highest economical mean pressure is obtained when the mixture is so proportioned that all the oxygen in the air combines with the hydrocarbons of the fuel. Faulty distribution may set up torsional vibration in the engine and insufficiently damped flexible couplings may suffer in consequence.

Distribution may vary in different cylinders, as a result of induction pipe design, roughness in passages, air leaks, etc. It is therefore usual to determine the correctness or otherwise of the mixture by the exhaust from the cylinder with the weakest mixture. Any large variation between the leanest and richest cylinder must have a bearing on the fuel consumption.

CO appears in the exhaust with a rich mixture and O with a weak one.

The products of perfect combustion are CO_2 and N_2, and the mixture of petrol to air should be about 1 to 15 by weight at ground level. H_2O is also present

If the carburettor is fitted with a power jet a check should be made to see that the jet does not come into operation so that the nine-tenths power fuel consumption reading is adversely affected. The effect of this jet is to give an economical cruising range to the carburettor, at the same time to provide ample enrichment for full throttle positions.

The position of the thermometer for taking air intake temperatures should be standardized for each type of engine, as the corrected brake h.p. may otherwise be inconsistent. The position should be such that the thermometer is unaffected by radiant heat. In cases where the air is heated by passing over an exhaust pipe the selection of the position is even more important. Air should be drawn from outside the test house, free from exhaust fumes and dust which blows up on windy days. The use of a fuel inferior to that approved for the type engine, or those containing Tetra Ethyl Lead, is not permitted, unless it has been authorized. The effect of the leaded fuel on certain materials sometimes used for valve seatings and valves is known to be detrimental. It is also well known that leaded fuel in the presence of water readily attacks magnesium alloy parts.

The presence of water in storage tanks can be readily detected by means of specially prepared strip paper having a brown preparation on one side.

The strip is attached to a bob weight at the end of a piece of string, lowered to the bottom of the tank, and left there for two minutes. If H_2O is present the preparation will disappear, leaving the paper white.

Fuel Pumps. There are two main types of fuel pump, the gear and the diaphragm. When gear type fuel pumps are fitted to engines it is important that fuel is circulated whilst the engine is running, as in many designs the fuel constitutes the lubricant for the moving parts. The use of pumps designed to supply fuel to a gravity tank might cause flooding if fed direct to the carburettor. In these cases the pump is cut out for bench tests, the fuel feed from the flowmeter being taken direct to the carburettor, the pump merely circulating fuel from a tank, a check being taken to prove that the pump is functioning satisfactorily by measuring the amount delivered over a given time. In

carrying out this check care is required to see that there are no air locks in pipe lines, or air leaks on the suction side of the system. Some makers fit two pumps, one giving a direct feed to the carburettor, and the other delivering fuel to a gravity tank in the machine. They might not function satisfactorily if reversed, as the capacities and delivery pressures may be different.

With diaphragm pumps any replacement or refitting of diaphragms will entail a re-check of fuel delivery.

The ignition system should not give much trouble, but magnetos, like other accessories, must be of approved type design. Engines are run on single ignition to check the extent of the drop in revolutions per minute. This should not exceed the schedule requirements. The test is carried out at full throttle and excessive drops in revolutions per minute may be due to dirty sparking plugs, or incorrect ignition timing. The effect of advancing the timing is normally to reduce the drop in revolutions per minute.

Sparking plugs should be maintained in a satisfactory manner, by periodic dismantling and cleaning, followed by a pressure test at 100 lb. per sq. in. for functioning on re-assembly. Dirty sparking plugs have a direct bearing on engine performance on the test bench, and erratic running and loss of power may be anticipated.

The change of oil from castor to the type approved for the engine should be effected whilst it is hot. New oil is added to the tank in the ordinary way, and the castor oil is drained from the engine sump until only fresh oil passes through. A better arrangement would be to have two separate tanks, one containing the vegetable and the other the mineral oil. The one is shut off as the other is turned on; mixed oil being drained off from the scavenge side of the system as before.

Test-House Equipment

Before we proceed with the acceptance tests of an engine we must see what knowledge the ground engineer requires with regard to the test equipment, and the nature and extent of the tests that are required and designed to assimilate to some extent the flight conditions.

The requirements of the Air Navigation Directions for the testing of normally aspirated engines, i.e. those rated for performance at full throttle at sea level, have been set out in detail in Design Leaflets C1, C2, and C3 of A.P. 1208, and it is important that the ground engineer becomes familiar with them in so far as they relate to subsequent engines. Paragraph 19 of Design Leaflet C2 deals with the general requirements of the test plant, and leaves the constructor a fair amount of latitude in the selection of apparatus suitable for any particular condition.

The first requirement is that "the brake shall be capable of varying the revolutions per minute at full throttle without stopping the engine." This allows for the power curves called for in the schedule, and data such as fuel consumption curves to be properly taken, and engine performance generally observed throughout the full range of speed.

A few particulars of dynamometers fulfilling the above requirements will now be given, but the ground engineer should have had practical experience of one of them.

HEENAN & FROUDE HYDRAULIC DYNAMOMETER. This is probably one of the best known and most extensively used. The power generated by the engine is transmitted through a coupling to a rotor. This rotor revolves in an outer casing through which water is circulated, and is mounted on bearings to permit free, though restricted, movement about its own axis. The resistance offered by the water to the turning of the rotor reacts on to the casing, which is maintained in horizontal balance by suitable weights suspended at the end of a balance arm attached to the casing. The internal resistance can be varied by means of sluices, and the water in circulation carries away the heat generated by the destruction of power. An independent cooling fan giving an air speed range of from 75 to 120 miles an hour over the engine, is used. The air speed is recorded by a water manometer, calibrated to record under a given set of conditions. In operating a strange brake, preliminary checks should be made of engine alignment, accuracy of weights and balance of the rotor casing with water in circulation, and engine uncoupled from the brake. The correct horizontal position is indicated by a pointer. A constant supply of water at a pressure recommended by the makers of the brake should be available, and no power readings should be taken outside the range for which the brake is designed.

The B.H.P. $= \dfrac{W \times N}{K}$.

N is the revolutions per minute of the airscrew shaft.

W is the load in lb. lifted by the arm.

K is the constant for the brake. If $\dfrac{1}{K}$ is unknown the formula for $\dfrac{1}{K}$ is $\dfrac{2 \times \pi \times L \text{ (ft.)}}{33000}$.

$L =$ length of the arm from the centre of the brake to the point of suspension of the weights.

THE HIGHFIELD ELECTRIC DYNAMOMETER. The engine in this case is coupled direct to the armature of an alternating current generator. The stator, or casing, of the generator is mounted on ball bearings, but is restricted in rotational movement, and provides, in effect, a swinging field. The power developed by the engine is measured by the torque reaction of the casing, which is connected by a short arm to a steelyard type of weighing machine, electrically operated. The torque can be controlled by variation of the electric circuit of the stator. The electrical power developed is used to drive a motor coupled to a fan supplying cooling air through a tunnel to the engine, any surplus energy being absorbed in outside circuits. It will be seen that the plant can be self-contained, but with an external source of electrical power the generator can be used as a motor for starting and running in an engine. The brake horse-power is calculated as previously described.

PLATE XV. GRINDING CYLINDER BORES

The cylinder *A* is screwed into the jig plate *B*, which is then bolted to plate *C* on the machine. Arm *E* carries a grinding wheel, which is driven by a shaft passing through the centre of the arm.
The cylinder is made to reciprocate backwards and forwards whilst rotating. The method of mounting the cylinder eliminates any possibility of mal-alignment, and the thickness of the walls is perfectly uniform after the operation.

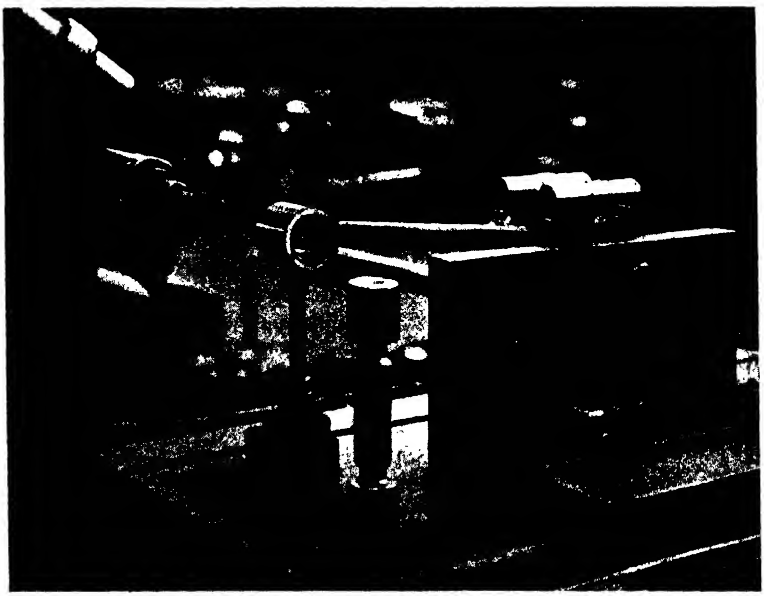


PLATE XVI. GRINDING THE EYE END OF A CONNECTING ROD
("Go" and "Not go" gauge in the foreground.)

HEENAN & FELL DYNAMOMETER. The engine is mounted on a centrally pivoted torque table, free to move within restricted limits. Attached to the torque table is an arm, from the end of which weights are suspended, and the reaction of the fan impellor, or rotor, fitted to the engine, is measured in a similar manner to the two dynamometers previously described. The fan impellor rotates in a casing which is provided with adjustable outlets, so that the engine load can bo varied by regulating the discharge of air.

A further requirement of Design Leaflet C2 is that "The h.p. developed by an engine shall be measured by the torque reaction of the engine." The three types of dynamometer already described conform to this requirement.

Engine Cooling and other Services

Paragraphs 19 to 32 of Design Leaflet C2 specify certain requirements during engine testing, such as cylinder cooling, fuel, oil and air intake conditions, etc.

We will, then, briefly consider each of these headings.

CYLINDER COOLING. This is probably a less serious matter with water-cooled than air-cooled engines, although in the former case excessive temperatures might cause steam pockets and resultant local trouble.

Normally the engine bench test is carried out at a uniformly maintained coolant temperature. To secure similar conditions in flight, a thermostat should be fitted in the coolant system. This relieves the pilot of the necessity to operate the radiator shutters because when the coolant temperature falls near say 75° C., the coolant is gradually by-passed from the radiator. When the coolant temperature has risen to say 95° C., the by-pass valve is shut and the system operates as a normal liquid-cooled engine.

Where liquid coolants are used, Ethylene Glycol is sometimes em ployed in place of water. This liquid has a boiling point of 185° C. and a freezing point of – 30° C. At 15,000 ft. it boils at approximately 160° C.

The liquid can only be used with safety up to 130° C., but as an engine would then be running hotter than with water as a coolant, loss of power might result, due to impaired volumetric efficiency. This drop in power is, however, more than offset by the reduced drag in the aircraft, by virtue of the fact that the radiator surface is halved.

Ethylene Glycol is expensive and must not be allowed to boil, in view of the possible loss by evaporation. If water is present, the temperature must be kept below 100° C., otherwise steam pockets may occur. It has a tendency to creep like paraffin, and all joints require special attention. It is also dangerous to the skin. It attacks ordinary rubber when hot, and special material has to be used. If it comes in contact with a hot manifold it ignites more readily than lubricating oil.

Some engines are compositely cooled, that is to say, water and steam are used. The water inlet temperature may be 95° C., and the outlet

temperature 105° C. The steam generated in the header tank is carried off to a condenser and returned to the water system, by means of an injector. Much heat is absorbed in converting the water into steam.

Pressures up to 3 lb. per sq. in. may be obtained.

Pressure cooling differs from composite cooling in that there is no condenser and the system is closed. A relief valve is inserted and set to blow off at from 15 to 30 lb. per sq. in. In practice a pressure of say 5 lb. per sq. in. may be expected on "climb" and up to 15 lb. per sq. in. operating in the tropics.

A failure of the system would result in excessive steaming.

Overheating, if associated with detonation can be partially suppressed by the use of an anti-knock fuel, and to a less extent by increasing the mixture strength, but on the test bench the cylinder temperatures of air-cooled engines are largely controlled by the volume and velocity of the cooling air, and for this reason it is usual to fit thermo couples on one or more of the hottest cylinders.

A couple is formed by the union of two dissimilar metals which, on being heated at the junction, generates an electric current sufficiently strong to be measured on a sensitive galvanometer or millivoltmeter.

For the range of temperatures normally recorded on aero-engine cylinders, couples, composed of constantin and copper are often employed. A cold junction box is usually inserted in the circuit. This contains the junctions where the wires from the couple are joined with those to the galvanometer, and as long as the two joints are maintained at the same temperature ($\pm$ 5°) any E.M.F.s set up will be equal and opposite, and no appreciable error will occur.

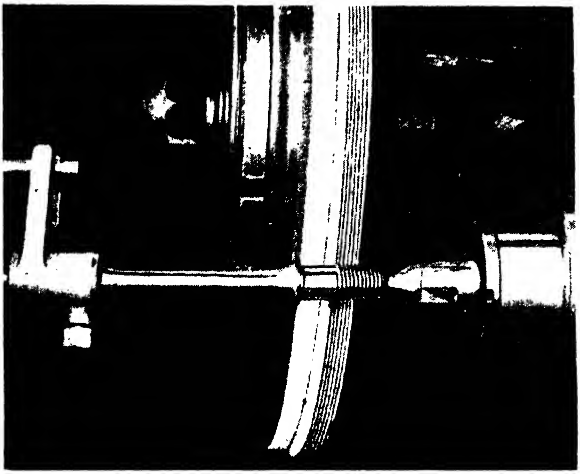
E.M.F. is generated when the couple is heated to a temperature different from that of the remainder of the circuit.

When the galvanometer is adjusted to read zero, the temperature of the couple and the cold junction should be the same. The difference in temperature of the cold junction above or below zero should be added to or subtracted from the galvanometer reading as the case may be, to get the true temperature of the body being measured. It will be seen that the temperature of the cold junction must remain constant. This is normally taken care of by fitting it into a thermos flask and in heat-treatment shops, by employing water-cooled cold junction boxes.

Most engines have provision in the cylinder heads for the "thimble" or buried type of thermo couple, but if no provision has been made, the ring type, which fits underneath the sparking plug, is available. There is, however, a risk of obtaining erratic readings with this type of couple, owing to leakage of hot gases and exposure to slip stream, and the thimble type generally gives more consistent results and will normally show temperatures 40° to 50° C. higher than with the ring type.

A periodic calibration of thermo couples, together with their respective leads and cold junctions, should be carried out. This can be done by using a block of aluminium into which the couple to be tested is screwed, care being taken to see that a good contact between the couple and the bottom of the hole is obtained. As near to the couple

as possible another hole is provided, into which a standard thermometer is inserted, surrounded by mercury. The aluminium block is heated uniformly by means of a Bunsen burner to 300° C., and as it cools down, readings of the couple under test are taken by means of a standard thermometer. A graph, showing temperature against E.M.F. or galvanometer reading, should be plotted.



By courtesy of *Messrs. Rolls Royce Ltd.*

PLATE XVII. GRINDING A SCREW THREAD ON A STUD

Ground screw threads are often specified for parts on modern engines, due to the difficulties in producing accurate threads on the special steels used, by other means.

The accuracy of ground threads is dependent on the grinding wheel. This has a number of ribs on its periphery, each of which is generated in turn to true form and pitch corresponding to the thread to be ground. The axis of the grinding wheel is off set to that of the work.

The initial trueing and periodic dressing of the grinding wheel is done by setting up a delicate micrometer cam box between the centres which hold the work. This box contains cam, stylus and holder for diamond dressing tools.

The face of the wheel is dressed first. Then a V-shaped diamond tool is fitted to the holder and the grooves are roughed out, finally with a finishing diamond tool, the exact shape of the grooves is generated.

Inspection of finished threads includes an examination of all elements on a Zeiss machine, by projecting the magnified image on to a screen on which a correct master thread is drawn; in addition close inspection for cracks is necessary.

Some instruments are fully compensated as regards cold junction temperatures, whilst others require adjustment prior to calibration. In both cases the instructions with the instruments should be followed.

It will be clear that when testing engines on the bench the tunnel air speed, recorded in miles per hour by pitot head or inches of Hg on a U-tube manometer, will give no indication of the air speed over the cylinder heads. This will be dependent on the form of cowling provided and the resultant spilling of air into the test house.

PLATE XVIII. INSPECTION OF MERLIN ENGINES AFTER ENDURANCE TEST

The engines are stripped, parts are washed and cleaned, and then laid out in specially designed trays, fifteen being required to accommodate one complete engine. One length of inspection conveyor is occupied. Cylinder blocks are dealt with in a separate shop with special conveyors.

The temperature of magnetos during test may easily reach 90° to 100° C., and in view of the moulded parts used in their construction, it is desirable to avoid these temperatures by providing suitable cooling.

OIL SYSTEM. Oil tanks should be of such a form that accurate readings can be taken. They should incorporate some form of auxiliary heating in order to maintain the oil inlet temperature at 70° C. during the test of the engine, care being taken that local heating does not occur, as otherwise there is a risk of impairing the characteristics of the oil.

The pipes would require to be lagged with asbestos for testing in the winter in exposed or open test houses, whilst in hot weather provision for cooling the oil would be necessary.

It is undesirable to cut down the quantity of oil in circulation during a test, and it is suggested that as a minimum the equivalent of six hours' consumption should be used.

Oil filters should be fitted on all test benches in addition to any filters already incorporated in the engine. They should be large and capable of filtering the smallest particles of foreign matter. If they are provided in duplicate it is possible to clean one whilst the other is in use. Tanks and pipe lines must always be clean if good bearings are to be obtained. Magnets are sometimes incorporated with the filters to collect ferrous particles in suspension. Oil is sometimes weighed to eliminate errors arising from frothing and aeration.

AIR INTAKE. Artificial heating to the air entering the carburettor during cold weather has been permitted in certain cases where the conditions are not more favourable than those in the aircraft in which similar engines are normally installed. No artificial draft is allowed to play on the air intake, and the position of the thermometer, dealt with elsewhere, is important.

FUEL SYSTEM. The fuel is measured by some form of flowmeter, such as the Brown and Barlow. With this apparatus fuel is supplied from a tank through a filter to the float chamber at the top of the instrument. The head of fuel should be as indicated by the makers, usually about 18 in. The float chamber connects with the body of the instrument by a vertical central tube. On either side of this lower chamber calibrated orifices are provided through which the fuel flow is controlled. Leading upwards from either side of the body two vertical glass tubes, open to the atmosphere at the top, are fitted. Adjusable scales, graduated to read in pints per hour, are mounted adjacent to the glass tubes. Cocks are fitted below each glass tube through which the supply of fuel is taken direct to the carburettors. When the cocks are closed, the fuel level in the glass tubes is the same as that in the float chamber. When they are open and the engine is running, the level of the fuel in the glass tubes registers the amount of fuel that is being consumed by the engine.

Periodical checks of the flowmeter are made by disconnecting the pipe leading to the carburettor, and checking the free flow by means of a stop watch and measuring vessel and comparing it with the scale reading. This should be done at several positions of the scale

by restricting the fuel flow. The S.G. of the fuel may affect the accuracy of the readings, so a change of fuel may necessitate re-calibration.

GAUGES. Equipment of this nature requires periodical checking and the following notes will be of assistance.

(i) Temperature gauges are checked against calibrated ball thermometers.

(ii) Pressure gauges are checked to a dead load instrument, or if this is not available, a gauge known to be accurate.

(iii) Depression gauges are checked by a vacuum pump or column of mercury.

(iv) Back pressure recorded in the manifolds can be checked against a mercury column.

(v) Some boost gauges have a movable scale, adjustment of which provides for changes of barometric pressure.

All observed b.h.p. figures must be corrected for variation of barometric pressure and air intake temperature. When exhaust manifolds are fitted there is a correction for back pressure in favour of the engine. Details of these corrections are given in paragraph 16 of Design Leaflet C1.

It will be found that an engine is usually given two b.h.p. ratings in the Type Certificate. The higher one is the rated power of the engine and the lower one the minimum power at which subsequent engines of the type may be accepted. The schedule of tests governing the acceptance of new and overhauled engines is detailed in paragraphs 46 to 52 of Design Leaflet C3, and it will be seen that under certain conditions it is unnecessary to test engines on a dynamometer. For this reason a ground engineer who had had no prior bench testing experience would have his licence restricted to the testing of engines with a test fan, or airscrew.

Testing with Airscrews

The use of a flight airscrew for prolonged engine running, on a fixed test bench, or in the machine, is unsatisfactory from the point of view of cooling the engine. Furthermore, the desired load at normal engine revolutions per minute cannot be obtained except by trimming the airscrew. For routine testing, therefore, a calibrated test fan is normally used which is designed to absorb approximately nine-tenths of the rated power of the engine at normal revolutions per minute. On opening up the engine to full throttle the revolutions per minute would increase by about 5 per cent, and it should be possible to establish this figure for each fan for a particular type of engine. Test fans, unless properly designed, are liable to permit an engine to overheat as a result of insufficient air speed and distribution. The test plant should be designed to give an effective air stream to sparking plugs and cylinder heads of air-cooled radial engines of not less than 85 miles per hour.

It should be remembered that power absorption figures of a test fan, calibrated on a spinning plant, may vary from those obtained on an engine, and two sets of figures may be seen on some drawings.

Airscrew and test fan calibrations should never be used for quoting

engine performances, as they must necessarily be only approximate, and even with careful storage when not in use climatic conditions may easily affect their characteristics. The environments of the test bed, and, in the case of open test houses, the effect of prevailing winds might also have a marked effect on their accuracy. Squally weather may affect the speed as much as 200 revolutions per minute. Wind blowing in the direction of the slipstream will tend to make the fan light.

Over-revving can also be produced by a change in design of exhaust manifold.

There is a growing tendency to use airscrew hubs incorporating an oscillation damper, and where such a device is standardized for a particular type of engine it must be considered as an integral part of the engine, and all testing, either with an airscrew, or on a dynamometer, must be done with a similar device fitted.

When testing supercharged engines with a test fan, the characteristics of which have already been ascertained on an engine known to be giving full power, the revolutions per minute, fuel consumption, and rated boost should be sufficient indications that the engine is satisfactory. A test fan is normally designed to absorb approximately nine-tenths of the sea-level power (760 mm. and 15° C.) at rated boost and normal revolutions per minute.

The boost gauge and pipe line must be free of air leaks, otherwise over-boosting may be recorded.

When variable pitch airscrews are fitted it is possible to obtain considerably more power from an engine by blade adjustment than when using a test fan designed to absorb nine-tenths power at normal revolutions per minute, and this point should be remembered.

The introduction of the variable or "controllable" pitch airscrew was necessary because with a fixed blade airscrew, whilst it might be correct for maximum speeds and efficient at cruising speeds where the density of the air is reduced, it would be incorrect for ground running and climb, the pitch being too great for the increased air density on or near the ground. By varying the pitch of the blades at will, this difficulty can be overcome and more power and engine revolutions can be obtained for climb.

One such airscrew is the "Hamilton" (2 pitch) made in this country by Messrs. The De Havilland Co., and it is possible for the blades to be set in one of two positions at will. The operation is effected hydraulically, the main engine oil supply being used in conjunction with a three-way valve which controls the oil supply to a jet in the extremity of the hollow airscrew shaft.

A piston is fitted to the end of this shaft and a cylinder, which moves forward due to the oil pressure, forms the front of the airscrew hub.

The blades are brought into the fine pitch position (for take-off and climb) as the cylinder is forced to its maximum outward position.

On cutting off the oil supply, the blades take up positions corresponding to the coarse pitch (for cruising) due to counter-balance weights (one on each blade) acting under centrifugal force, and which

are also sufficient to overcome the natural tendency of the blades when rotating, to revert back to fine pitch positions. The minimum oil pressure required to operate the airscrew blades is determined for each engine during the Type Test and is declared by the makers of the engine. The base setting of the blade angles is controlled by the position of the counter-weight bracket, on which a datum line is marked.

The adjusting stops for the high and low pitch blade settings, which are adjustable independently, are incorporated inside each of the counter-balance weights. All blades must be adjusted to exactly similar settings to prevent cylinder wear.

The range of blade angle movement is normally 10°, but sometimes 20°. The failure of the mechanism to operate may be due to—

(i) A blocked oil system due to presence of carbon or other causes.

(ii) Failure of booster pump, if fitted, or main engine oil supply.

(iii) Wrong balance weights.

Constant speed V.P. airscrews are operated in conjunction with an engine-driven governor which controls the oil supply operating the blades. A booster pump may also be incorporated in the unit. The load imposed by the governor spring can be adjusted by a rack and pinion mechanism or other means, and an extension to the rack is utilized to provide a remote control enabling the airscrew to run at any predetermined speed.

Hunting, oil pressure surge, overrun, etc., may occur when suddenly opening the throttle, but the speed should stabilize itself in a few seconds.

Low oil pressure and temperature will tend to make the change of pitch sluggish.

An engine which functions with a V.P. airscrew should be so tested that the tightness of glands, pipe lines and cocks, associated with the operation of the airscrew, are also checked. In the absence of an airscrew, a rig should be used for the purpose. This requirement is specified in Notice to Aircraft Owners and Ground Engineers, No. 20/1937.

V.P airscrews are treated as complete units and can only be overhauled by ground engineers possessing an "X" licence.

If the test house is situated at an altitude, the power absorbed by a test fan would be less than at sea-level, due to the difference in air density. A fan would be required, designed to accommodate these special conditions. It should be realized that variations in temperature and pressure would necessitate some tolerance or latitude in the acceptance of engines, and figures would be established according to the circumstances.

Engine Strip and Final Test. During the endurance test, oil and fuel consumptions are taken and a power check is effected at the end of the test. Oil leaks, vibration, irregular running, flat spots, etc., are looked for so that rectifications can be effected prior to the final test.

The extent of stripping to be done will be dependent on the amount and nature of replacements during the overhaul. Inspection will be

particularly directed to new and rectified parts and should follow the lines already detailed for the initial inspection.

Prior to the final test the engine should be carefully run up in incremental stages after which final tuning should be effected.

This may include the following—

(i) Adjustment of slow-running jets and throttle stop. When checking the minimum r.p.m. by adjusting the brake load to maximum cruising boost and normal r.p.m. and then throttling down, the r.p.m. in the aircraft may show an increase and adjustment would then be necessary. This is due to the brake characteristic and could be avoided if the setting was made at a given brake loading.

(ii) Check on entry of enrichment jet, if fitted.

(iii) Functioning of mixture control.

(iv) Carburettor flooding at maximum fuel head.

(v) Single ignition check for drop in revolutions per minute. This may vary on each magneto and should not normally exceed 5 per cent.

(vi) For the rated altitude check on a supercharged engine, the fuel supply is reduced manually if the carburetter is the pressure balance type, in effect the float chamber is connected with the air intake and the fuel supply is under ground level pressure before adjustment.

The final test is a proof run to prove reassembly of parts, but a three-point power curve is often taken if the test is effected on the brake. If the test is done with a calibrated fan, a full throttle reading and the revolutions per minute obtained is recorded.

A final inspection should follow the final test. This would include a check for completeness to the installation drawing and to ensure that pipe unions are tight, nuts are locked and split-pinned, controls are all working freely, etc.

If the engine is likely to be placed in store for some time, cylinders should be sprayed with mineral oil or a rust inhibitor. All orifices should be adequately covered, and external steel parts liable to rust should be treated with a coating of suitable rust preventive.

On completion of the overhaul and test of an engine, a certificate in the prescribed form must be entered in the log book and signed by the ground engineer. Details of the work carried out and the new parts fitted should also be included. The certificate implies that there have been no departures from the type drawings other than subsequent modifications which have been approved.

An entry should also be made detailing all the work carried out, any concessions that have been made, and a list of new parts fitted, together with the release note numbers.

Superchargers

To compensate for the loss of h.p. at altitude resulting from the decrease in density of the air, and resultant lack of oxygen required for properly burning the liquid fuel supplied to the engine, two methods have been adopted to overcome this difficulty—

1. The use of super-compression engines in which high compression ratios are used to obtain an increase in power.

2. The use of a supercharger unit in which the pressure of the mixture in the induction system is raised or "boosted," thus admitting a greater weight of charge into the cylinder on the induction stroke.

Neither of these schemes is in general use on civil engines, although there are a few types embodying one or the other, and the ground engineer wishing to add them to his licence must be fully conversant with the construction, functioning, and testing of these engines. With regard to super-compression engines, there are no special constructional features—apart from a gated throttle to prevent excessive detonation at take-off speed—which have not already been dealt with, but when we come to the supercharger type we do find some important changes. There are several forms of supercharger units, but for civil aircraft purposes we need consider only the mechanically driven centrifugal supercharger incorporating a rotor between the carburettor and engine. When the rotor is driven at crankshaft speed it is sometimes termed a "paddle fan," and is really a means of obtaining better distribution. When it is driven from four to six times the crankshaft speed it is known as a moderate supercharger, and when it is driven about 12 times the crankshaft speed it becomes a fully supercharged type.

The rotor, turning at anything up to 30,000 revolutions per minute, gives the mixture a high velocity which becomes converted into pressure head as it leaves the tips of the rotor vanes and by this means the induction pressure is raised above that of the surrounding air.

The main limiting factor in supercharging, in order to get maximum power and fuel economy, is the anti-knock value of the fuel. Supercharging raises the temperature and pressure of the mixture entering the cylinders, both of which encourage detonation.

There is a limit to the rated altitude with a single speed supercharger unit and a two-speed rotor would permit the rated altitude to be considerably raised if the correct ratios were selected.

Two-speed superchargers are in use on several types of engine and provide a moderate supercharge up to say 5000 to 6000 feet altitude and a full supercharge up to from 12,000 to 15,000 feet. The take-off and preliminary climb on low gear compared with the high gear, permits a much larger power to be available for the same boost and speed, whilst the high gear with the increased boost is available for the higher altitudes. To take-off on high gear would necessitate a much higher boost pressure to give the same performance, with more risk of detonation due to the greater temperature rise in addition, to increased mechanical loss in driving the rotor at the higher speed. This might be as much as 10–15 per cent, and that for loss of thermal efficiency due to high induction temperature may be nearly as much. The fuel economy on low gear is very great because there are no enrichment jets in operation and the mechanical loss in driving the rotor of the supercharger is not excessive.

The ground engineer must familiarize himself with the details, such as slipping clutches, spring drives, etc., incorporated, in order to avoid risk of failure due to sudden acceleration, deceleration, back-fires, etc.

Slipping clutches usually comprise a number of pads incorporated in one of the driving gears. The pads wedge in an annular groove in

the gear wheel under centrifugal loading. If the pads are badly worn there is a possibility that one or more may bottom in the groove. If this occurs, low or fluctuating boost pressures may be expected.

The schedule of tests for the acceptance of normally aspirated engines, Design Leaflet C3 (A.P. 1208), does not cover engines in the supercharger class, which are rated at full throttle at an altitude, and whilst Leaflets C1 and C2 are framed to cover the classification, and the general testing requirements, of both types, the actual schedule of tests is not provided. Pending the issue of Design Leaflets C4 and C5 for super-compression and supercharged engines respectively, it is usual for constructors to apply the existing service engine schedule in conjunction with Design Leaflet C1 and C2.

Design Leaflet C1 defines the terms the ground engineer must become familiar with in supercharger testing such as rated boost pressure, maximum permissible boost, rated altitude, sea level power, gated throttle power, and full throttle power.

The Service Schedule is known as A.P. 840. Paragraph 6 of Addendum A, deals with "subsequent" supercharged engines, and Addendum B deals with super-compression engines.

The ground engineer who is familiar with the testing of normally aspirated engines should be able to carry out most of the testing required in part 6 of the supercharger schedule, but it is thought that the sequence of corrections necessary in order to arrive at the "corrected" rated power might present some difficulty, and the following notes may be of assistance.

To Ascertain Engine Performance at Ground Level and at a Specific Altitude

The admission of air to the air intake of the carburettor must be controlled in order to maintain a pressure equivalent to the atmospheric pressure at the altitude at which it is desired to run the engine. It is under this condition that observations will be taken in order that the performance of the engine can be eventually established. The data to be observed are: Air intake depression. Air intake temperature. Induction pipe pressure or boost pressure, and b.h.p.

Standard air temperatures at the various altitudes are assumed, and that corresponding to the particular altitude is used in the calculation for ascertaining the "corrected" compression ratio of the supercharger or blower unit fitted.

In order, then, that the pressure corresponding to a particular altitude can be maintained at sea-level test bed conditions, a steel box having two openings is used. From one of these a large pipe leads to the air intake of the carburettor, the other being open to the atmosphere. An adjustable slide or valve is fitted inside the box between these two openings, so that the amount of air admitted to the carburettor can be controlled. A small pipe is connected at a point between the valve and the air intake of the carburettor, which communicates with a Mercury U tube. A shuttered hole for the periodical insertion of a thermometer is also provided.

In order to maintain the desired altitude pressure in the box, the barometer reading of the day is ascertained and the corresponding barometric pressure at altitude subtracted from it. The "difference" is the "depression," which must be recorded on the U tube when the engine is running at normal revolutions per minute at full throttle and power, with the control valve of the box suitably adjusted.

It is to be noted that the area of both orifices, and the pipe leading to the air intake should be such that, when the control valve is fully open, no depression will exist at the air intake. This will enable an engine to be run at ground level atmospheric pressure without the necessity of removing the control box.

Correction of the Compression Ratio of the Supercharger. The compression ratio of the blower or supercharger would be increased if the air intake temperature was reduced, which is the case when running at altitude, but as the engine is being tested at ground level with the air intake restricted to a predetermined altitude pressure, it follows that the air entering the intake will be at a higher temperature than that at the altitude concerned. The observed ground level air temperature in conjunction with the air temperature at altitude enables the required "correction" to be made.

Rated Boost Pressure. In order to obtain the actual boost pressure at altitude it is necessary to correct the observed boost pressure. This is necessary as a result of the increased compression ratio of the supercharger under altitude conditions as explained in the previous paragraph.

Correction of Observed h.p. for Rated Boost Pressure. The b.h.p. is assumed to vary directly with the absolute pressure in the induction pipe. It is apparent, therefore, that a correction is necessary as a result of the increased compression ratio of the supercharger at altitude, as against the observed or ground level reading. This correction is proportional to the corrected absolute pressure in the induction pipe divided by the "observed" absolute pressure.

Ground Level Power. In the preceding paragraph we have established the b.h.p. of the engine when running at the observed sea-level temperature, but boost as at rated altitude. We now want to find the b.h.p. which the engine will develop at the same rated boost pressure, but with the air intake corrected to a standard temperature of 15° C.

All powers are corrected for air intake temperatures to the square root of the absolute temperatures, and the b.h.p. multiplied by a correction factor will give the ground level power, and it is to be remembered that endurance tests are run at nine-tenths of the ground level power.

Correction of Ground Level Power for Air Intake Temperatures at the Rated Altitude. If this correction is to be accurate, the temperature of the mixture or charge in the induction pipe should be ascertained. This is difficult to carry out because engines are not usually provided with a means of observing this temperature. The rise in temperature due to supercharging is, therefore, ignored, and the air intake temperature is used.

Correction of b.h.p. for Difference in "Charge" and

"EXHAUST" PRESSURE AT ALTITUDE. This correction is necessary owing to the reduced atmospheric pressure at altitude which provides a lower pressure for the burnt gases to exhaust into. In other words, the "back pressure" on the pistons will be less at altitude than at sea level, and the power of the engine would, therefore, be slightly greater. A formula is given in the schedule of tests to establish the corrected b.h.p. This will give the rated full power at rated altitude at rated boost.

The following example is included to indicate the applications of the formulae and tables forming part of the Schedule of Tests in A.P. 840, Appendix "A."

ASSUMED RATING OF AN ENGINE—

310 b.h.p. at 3500 r.p.m. at 7000 ft. altitude.
Rated boost + 1¼ lb. (+ 2.5 in. Hg.).

OBSERVED DATA—

Brake h.p.: 280.
Air intake temperature: 25° C.
Barometer on the day: 29·5 in. Hg.
Air intake depression: − 6·41 in. Hg. (adjusted).
Pressure in induction pipe: + 2 in. Hg.

The following symbols are used in the formulae—

p_o = Observed pressure in the induction pipe (absolute).
p_l = Observed pressure in the air intake (absolute).
p_c = Corrected pressure in the induction pipe at altitude Z.
p_z = Air intake pressure at altitude Z.
t_o = Observed temperature at air intake (° C.).
t_z = Air intake temperature at altitude Z (° C.).
(From Table A at 7000 ft. $p_z = 23{\cdot}09$; $t_z = +\ 1{\cdot}14$° C.).

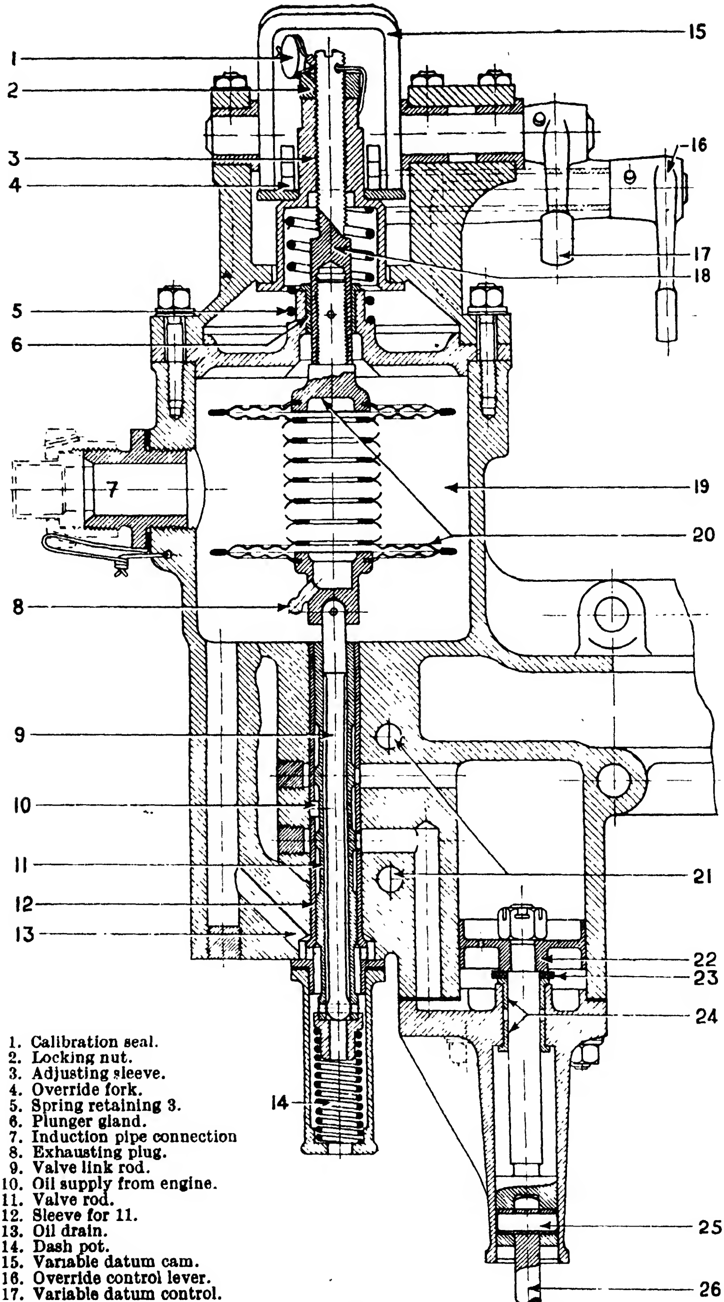
CORRECTION FOR COMPRESSION RATIO OF THE BLOWER—

Observed compression ratio—

$$r_o = \frac{p_o}{p_l} = \frac{(29{\cdot}5 + 2)}{(29{\cdot}5 - 6{\cdot}41)} = \frac{31{\cdot}5}{23{\cdot}09} = 1{\cdot}365 \qquad \text{(i)}$$

Corrected compression ratio—

$$r_z = \frac{p_c}{p_z} = r_o\,[1 + 0{\cdot}00063\,(r_o)^2\,(t_o \quad t_z)] = 1{\cdot}365\,[1 + 0{\cdot}00063\,(1{\cdot}365)^2\,(25 - 1{\cdot}14)] = 1{\cdot}404 \qquad \text{(ii)}$$



1. Calibration seal.
2. Locking nut.
3. Adjusting sleeve.
4. Override fork.
5. Spring retaining 3.
6. Plunger gland.
7. Induction pipe connection
8. Exhausting plug.
9. Valve link rod.
10. Oil supply from engine.
11. Valve rod.
12. Sleeve for 11.
13. Oil drain.
14. Dash pot.
15. Variable datum cam.
16. Override control lever.
17. Variable datum control.
18. Aneroid plunger.
19. Aneroid chamber.
20. Aneroid.
21. Scavenge oil ports.
22. Servo piston.
23. Minimum power stop washer.
24. Bush for oil gland.
25. Crosshead.
26. Rod to toggle link.

By courtesy of H. M. Hobson, Ltd.

FIG. 9. VARIABLE DATUM BOOST CONTROL

CORRECTION TO OBTAIN RATED BOOST PRESSURE—

$$p_s = p_l \text{ and } r_z = \frac{p_c}{p_z}$$

$$\begin{aligned} \therefore p_c &= r_z \times p_z \\ &= 1{\cdot}404 \times 23{\cdot}09 \\ &= 32{\cdot}42 \text{ in. or } (32{\cdot}42 - 29{\cdot}92) \\ &= +\,2{\cdot}5 \text{ in. Hg.} \quad . \quad . \quad . \quad . \quad \text{(iii)} \end{aligned}$$

CORRECTION OF OBSERVED POWER FOR RATED BOOST PRESSURE—

$$\begin{aligned} \text{Corrected b.h.p.} &= \text{b.h.p.} \times \frac{r_z}{r_o} \\ &= 280 \times \frac{1{\cdot}404}{1{\cdot}365} \\ &= 288 \text{ (approx.)} \quad . \quad . \quad . \quad . \quad \text{(iv)} \end{aligned}$$

THEORETICAL GROUND LEVEL POWER—

$$\begin{aligned} \text{G.L. Power} &= \text{b.h.p. (corrected)} \times \sqrt{\frac{273 + t_o}{273 + 15}} \\ &= 288 \times 1{\cdot}0174 \\ &= 293 \text{ (approx.)} \quad . \quad . \quad . \quad . \quad \text{(v)} \end{aligned}$$

($t_o = 25°$ C. and Table C gives factor 1·0174 for this temperature.)

CORRECTION FOR AIR INTAKE TEMPERATURE AT 7000 ft. ALTITUDE—

$$\begin{aligned} \text{b.h.p.} &= \text{G.L. power} \times \sqrt{\frac{273 + 15}{273 + t_z}} \\ &= 293 \times 1{\cdot}025 \\ &= 300 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(vi)} \end{aligned}$$

($t_z = +\,1{\cdot}14°$ C. and Table A gives factor 1·025 for this temperature).

CORRECTION FOR EXHAUST BACK PRESSURE AT 7000 ft. ALTITUDE—

$$\text{Factor for rated full power at 7000 ft.} = \frac{100 + \dfrac{(760 - p_z\ m/m.)}{35}}{100}$$

$$\begin{aligned} \text{or from Table A} &= 1{\cdot}050 \\ \text{Rated full power} &= 300 \times 1{\cdot}050 \\ &= 315 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(vii)} \end{aligned}$$

Boost Controls

If an engine is fitted with an automatic boost control a knowledge of the principle, construction, functioning, and adjustment is required. A few notes on these points may, therefore, be of assistance.

OBJECT OF THE BOOST CONTROL. When running an engine at sea level up to rated altitude the rated boost pressure cannot be exceeded even though the throttle lever is fully opened.

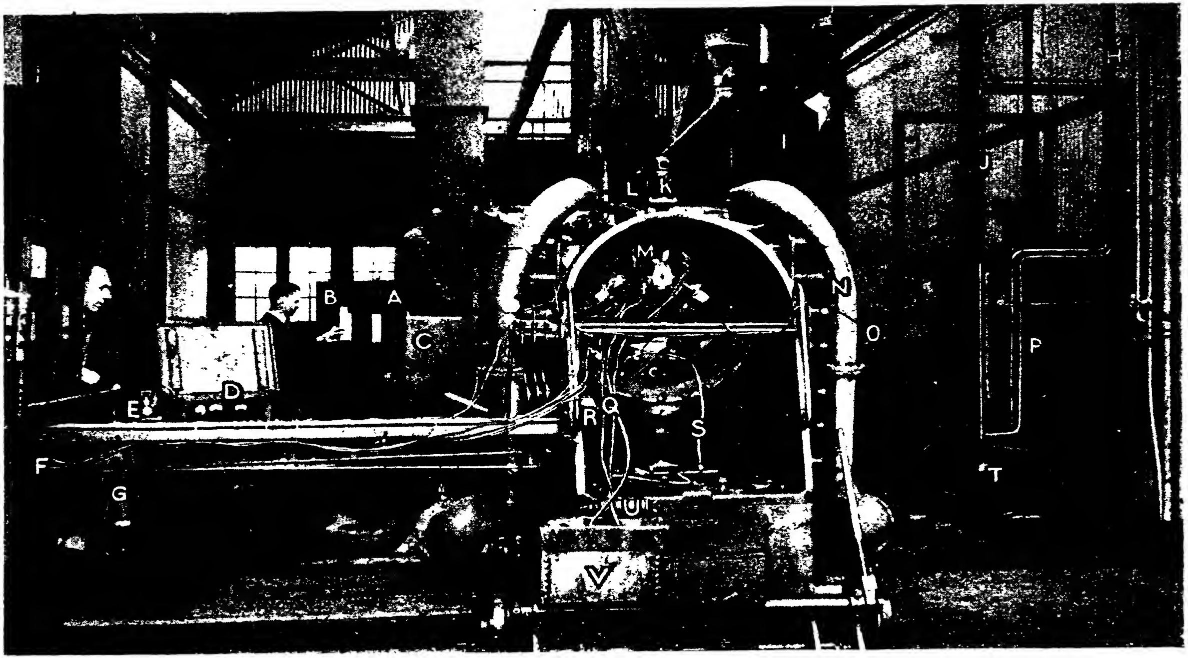


PLATE XIXA. TIGER ENGINE ON TEST (Rear view)

A = Mercury column (Boost pressure).
B = Mercury column (air intake depression).
C = Depression box.
D = Voltmeter and ammeter for generator.
E = Viet hand starter and compressor.
F = Leads from couples in cylinder heads.
G = Compressed air bottle.
H = Pressure of steam to oil tank.
I = Expansion chamber for exhaust gases.
J = Thermometer for oil inlet temperature.
K = Engine-driven generator.
L = Tube supplying cooling air to generator.
M = Engine-driven compressor.
N = Exhaust collector.
O = Tapping for measuring back-pressure.
P = Steam-heated oil tank.
Q = Pipes to and from fuel pumps.
R = Primer pump.
S = Fuel feed pipe from flow meter.
T = Oil cooler.
U = Test bench fuel filter.
V = Petrol tank for fuel pump circulation.

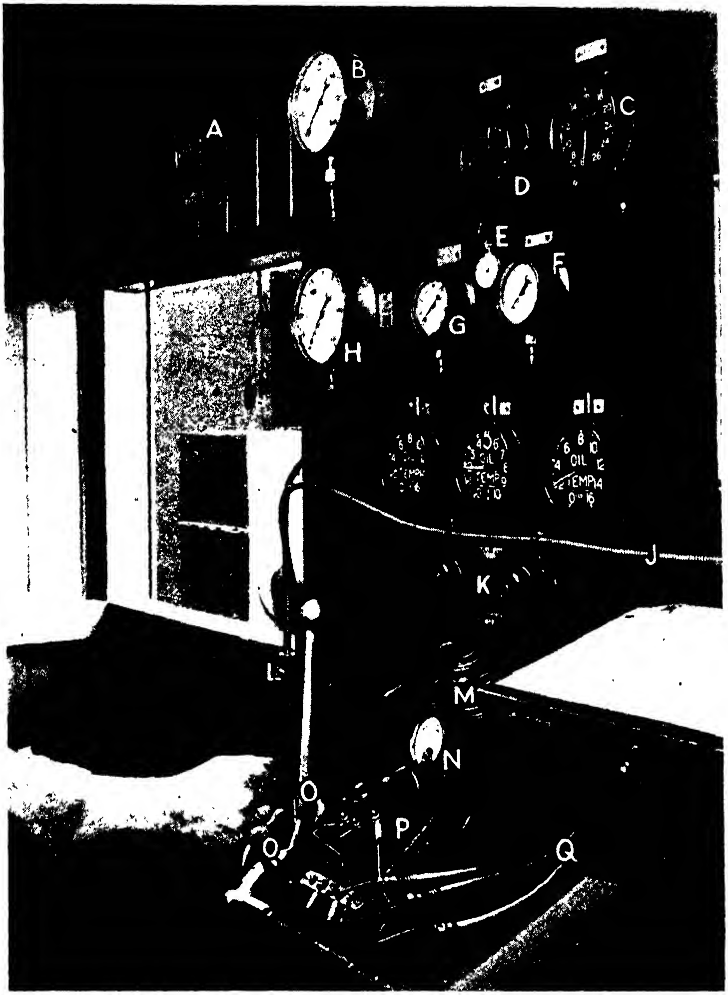
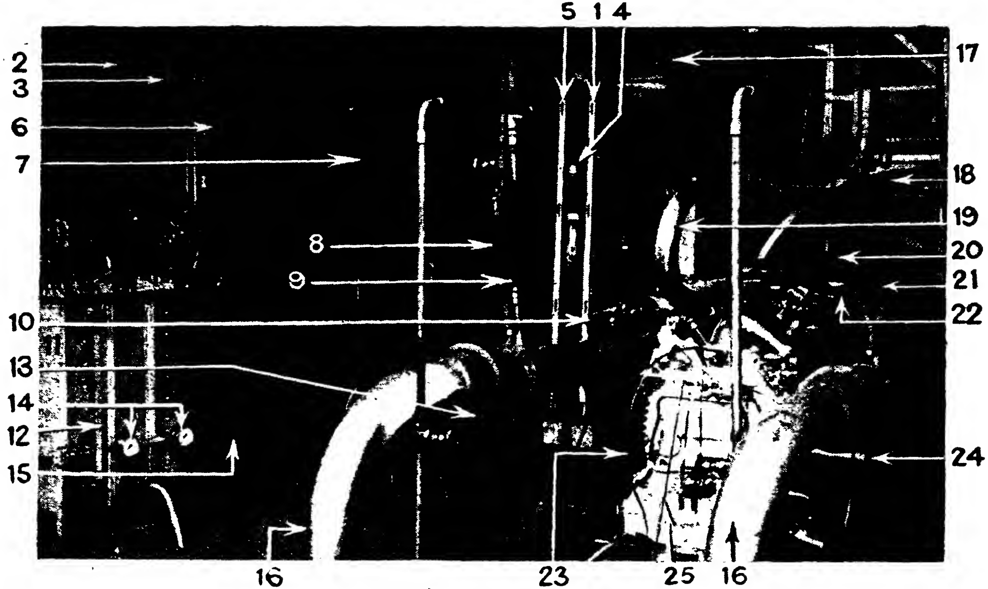


PLATE XIXB. ENGINE TEST BENCH CONTROL CABIN

A = Pressure gauge for petrol pump.
B = Oil scavenge pressure gauge.
C = R.P.M. indicator.
D = Air speed indicator.
E = Watch.
F = Main oil pressure gauge.
G = Crankcase oil pressure gauge.
H = Air compressor gauge.
I = Transmitting type oil thermometers.
J = Flexible drive for Hasler.
K = Engine switches.
L = Tachometer two-way box.
M = Cold junction for thermo couples.
N = Galvanometer for recording temperatures.
O = Engine controls.
P = Thermo couple distribution box.
Q = Thermo couple leads.



By courtesy of *Messrs. Rolls Royce Ltd.*

PLATE XIXC. MERLIN ENGINE ON TEST

The coolant tank and depression box are at the back of the plant.

1. Boost U tube.
2. Flowmeter (small).
3. Flowmeter (large).
4. Silencer back pressure U tube.
5. Air intake depression U tube.
6. Check flowmeter.
7. Control cabin.
8. Water spray into exhaust pipe.
9. Water pipe for silencer cooling.
10. Pipe from R.A.E. compressor to pressure gauge in cabin.
11. Oil tank.
12. Oil gauge (direct reading).
13. Pipe to silencer (back pressure).
14. Vacuum gauges.
15. Float chamber (representing aircraft tank).
16. Water jacketed exhaust pipes.
17. Water pipe for silencer cooling.
18. Tunnel for cooling fan.
19. Coolant pipe (engine cooling).
20. Water spray into exhaust pipe.
21. Water pipe for silencer cooling.
22. Pipe from B.T.-H. compressor to pressure gauge in cabin.
23. Pipe to boost U tube.
24. Starting handle bracket.
25. Throttle control (operated from cabin).

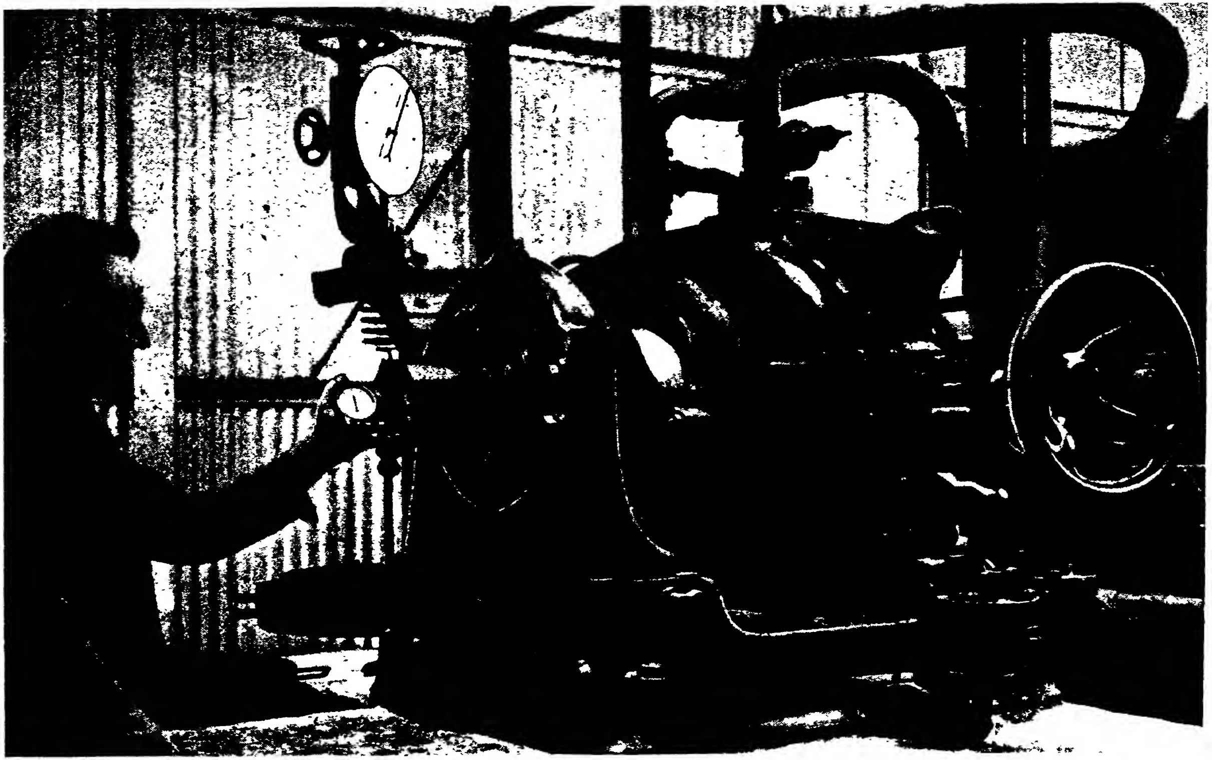
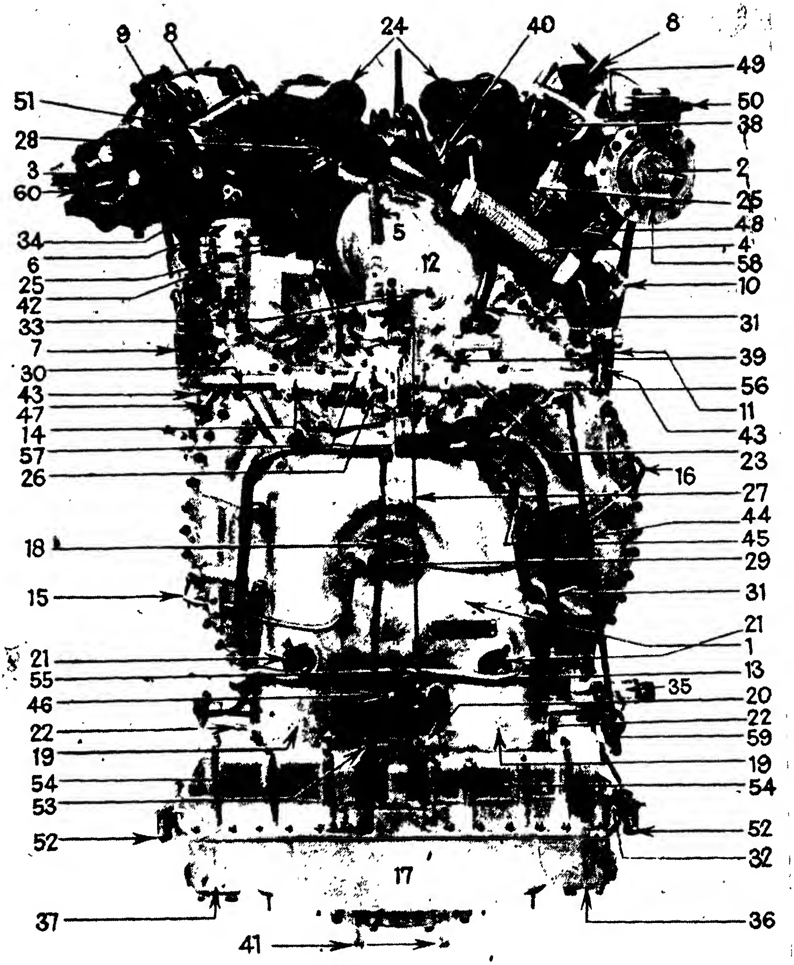


Plate XIXd. Checking Engine R.P.M.

The airscrew shaft speed is checked at intervals with a Hasler revolution indicator or similar apparatus. It is sometimes more convenient to check the speed at the end of the brake shaft as in the illustration.



By courtesy of Messrs. Rolls Royce Ltd.

PLATE XX. ROLLS ROYCE S.U. CARBURETTOR AND MERLIN SUPERCHARGER

Key to Plate XX

1. Supercharger casing.
2. B.T.-H. Compressor.
3. R.A.E. Compressor.
4. Ignition harness.
5. Petroflex priming pipe.
6. Boost control (fixed datum).
7. Magneto (port).
8. Rocker covers.
9. Tachometer drive.
10. Screened sparking plugs.
11. Magneto (starboard).
12. Induction pipe from supercharger.
13. Return oil pipe (throttles to sump).
14. Control shaft bracket.
15. Pipe connecting pressure and suction sides of supercharger.
16. Low pressure oil supply to rotor bearings.
17. Carburettor base.
18. Accelerator pump control rod.
19. Throttle edge jets (slow running).
20. Throttle stop.
21. Core plugs (to facilitate casting).
22. Adjustment for slow running.
23. Control shaft bracket and coolant connection.
24. Coolant pipes (outlet).
25. Camshaft inclined drive.
26. Differential gear (control shaft).
27. Throttle control rod.
28. Induction manifold.
29. Rotor shaft bearing (rear end).
30. Main control shaft.
31. Coolant pipe (choke heating system).
32. Boost pipe to aneroid chamber.
33. Boost gauge connection.
34. Low pressure oil feed pipe to camshaft.
35. Relief valve (throttle heating system).
36. Automatic mixture control aneroid chamber (boost operated).
37. Automatic mixture control aneroid chamber (altitude operated).
38. Spare drive.
39. Stop for throttle in open position.
40. Volute drain (petroflex).
41. Main jets.
42. Emergency cruising control cut out.
43. Magneto control (connected with throttle).
44. Economical cruising control rod.
45. Taper plug (blind flying attachment).
46. Butterfly shaft and glands.
47. Pipe from supercharger to boost control.
48. Low pressure oil feed pipe to camshaft.
49. Air inlet to compressor.
50. Air outlet to bottle.
51. Spare drive.
52. Drain cock (choke heating system).
53. Accelerator pump control adjustment.
54. Variable jet link mechanism cover.
55. Throttle control rod adjustment.
56. Cockpit control connection to 44.
57. Cockpit control connection to 30.
58. B.T.-H. Compressor oil level valve.
59. Economical cruising control rod adjustment.
60. Oil pipe connection from filter.

Construction. A large sealed cylinder, or chamber, fitted with a union for a pipe connection to the induction casing, contains an aneroid comprising 8 exhausted capsules. One end of the aneroid is connected to a piston valve, the other end has a screwed rod attached to it which protrudes through the end cover of the chamber. The screwing in or out of this rod constitutes the aneroid adjustment, which, when established, is locked by a second nut.

The other end cover of the chamber, through which passes the valve shaft, incorporates a piston valve sleeve which, by means of transfer ports and passages, admits oil from the main engine system to the top or bottom side of a piston fitted to a small cylinder, as required. waste oil is conducted to the scavenge system of the engine.

A small hole is drilled in the piston crown to allow a permanent oil leak to prevent a possibility of freezing at high altitudes. The quantity of oil lost is negligible in comparison with the normal flow through the transfer ports.

The piston valve is provided with a spring-loaded dash pot to prevent valve oscillation.

A connecting rod attached to the piston passes through a gland, and is then connected through suitable toggle mechanism to the throttle control shaft on the carburettor.

Functioning. As the aneroid chamber is connected to the induction casing, the pressure in both will always be the same. Therefore, when any change in boost pressure occurs, the aneroid will expand or contract according to whether the pressure is negative or positive. Any movement of the free end of the aneroid moves the piston valve a corresponding amount, so controlling the flow of oil either to the top or bottom of the piston in the cylinder. The oil from the negative pressure side of the piston passing through an outlet port uncovered by the piston valve.

The toggle mechanism permits the throttle lever to go to the full open position at ground level without the possibility of the permissible boost being exceeded. As the rated altitude is approached the link rod is gradually straightened out by the operation of the piston, until at the rated altitude the pilot's throttle control will still be in the full open position, but the carburettor throttle will be full open also.

Minimum Power Stop. In order to safeguard the pilot in the event of a failure of the boost control unit, or the oil supply to the unit, provision is made to ensure that there is sufficient power available for this eventuality.

This is done in various ways on different units. In one type a washer is inserted under the piston to limit the downward travel so as to give a predetermined power when the throttle lever is full open. This power is normally just below rated boost at standard atmospheric pressure.

It should be noted that washers are not interchangeable between one engine and another.

In another type of boost control a peg is fitted to the piston crown or cylinder head to limit the upward movement of the piston. This must be adjusted for each engine, and if it is too long it may easily affect the initial setting of the aneroid.

ADJUSTMENT. This should be made when the engine is warm. The throttle should be gradually opened until a pressure slightly in excess of the desired rated boost is obtained, and then kept in this position. The aneroid should then be adjusted until the rated boost pressure required is recorded on the gauge, when the adjuster is locked. It will be found that one-sixth of a turn is equivalent to about ¼ lb.

A check can be made of the adjustment by easing back the throttle lever and again opening up. If the setting is correct, the throttle lever can be opened to full travel, the boost control having charge of the throttle, so preventing a pressure rise in excess of rated boost.

At this boost, the piston takes up a position between its extreme limits of movement and, if oil-operated, may pass as much as 35 gallons of oil an hour, on a high power engine.

Boost Over-ride Control and Enriching Device

Before the present over-ride control was available, some engines were fitted with carburettors incorporating mixture controls set initially weak at the normal rich position. It was then possible to move the mixture control lever through a gate to obtain the normal rich mixture for take-off and throttle openings when the power jet was not in operation.

OBJECT OF, AND LIMITATION TO, OVER-RIDE. The over-ride mechanism is incorporated in the automatic Boost Control so that maximum permissible boost can be obtained for purposes of "take off" and "climb" if the type engine has been approved to include this. It relieves the pilot of the necessity of watching his boost gauge.

Maximum permissible boost obtained in over-ride varies with the engine revolutions, as it is dependent on the compression ratio of the blower unit, which also varies with engine revolutions.

It should be clear that over-ride is only provided for "take off" and in some cases "climb," and it should not be possible to exceed normal engine r.p.m. in climb other than with a variable pitch airscrew.

With some engines in which the M.P.B. is practically at full throttle at normal engine r.p.m. the carburettor throttle can be fully open without obtaining M.P.B. if the barometric pressure for the day is low. This should not be overlooked when setting the over-ride.

If over-ride is maintained on a climb there may arrive an altitude where loss of power will occur due to over-richness. In such cases, unless an automatic mixture control is incorporated, it may be necessary to revert to the rated boost position of the control which is in effect weakening of the mixture by cutting off the extra fuel provided in override, and referred to later.

CONSTRUCTION. Over-riding or delaying the action of the boost control may be accomplished in three ways—

(i) Mechanically, by providing mechanism to vary the aneroid datum, so causing the pressure to rise in the induction system.

(ii) Some engines obtain maximum permissible boost by passing the throttle lever through a gate, set at rated boost, until it comes to a stop which limits the throttle movement.

If the stop is set to a boost gauge, correction for the barometric

pressure of the day must be made. If the stop is set when the engine is on the test bed, a mercury column is used. A trap, however, should be inserted, to protect the engine against mercury being sucked in at small throttle openings.

(iii) By spilling the contents of the aneroid chamber.

In the latter case the pipe from the pressure side of the induction system connects with the aneroid chamber through a calibrated sharp-edged orifice which restricts the quantity of air passing into the chamber.

A venturi is also fitted to a union in the aneroid chamber, and a pipe from this passes to a valve and thence to the suction side of the supercharger.

This valve is opened when over-ride is brought in and for this purpose the mixture control lever is arranged to pass through a gate backwards beyond the full rich position.

FUNCTIONING. When the valve is closed the boost control functions normally. When the valve is opened the pressure acting on the capsules is relieved a predetermined amount owing to the fact that the venturi, being larger than the calibrated orifice, tends to spill more air from the chamber than is entering into it via the calibrated orifice. This allows the aneroid to extend and, via the servo motor and links, open the throttle more and more to give a higher power. The boost continues to rise until equilibrium is maintained in the aneroid chamber.

When the over-ride is in operation it is not possible to use the mixture control, but in order to safeguard the engine against possible detonation a rich mixture is provided by means of an additional supply of fuel. This is done by a separate aluminium casting containing a spring loaded piston valve and a metering jet. It comes into operation at the same time as the over-ride, and provides an increase in mixture strength of about 12 per cent.

VARIABLE DATUM BOOST CONTROL. When closing the throttle from rated boost the pilot's lever would start to move backwards, each movement of the pilot's lever would close the throttle, which would reduce the boost pressure in the aneroid chamber, which, in its turn, would extend the capsules and thereby expose the appropriate side of the piston to oil pressure. The movement of the piston alters the angle and thereby the length of the toggle links and so opens the throttle again. This would continue until the piston had reached the other end of its stroke and the toggle links between the pilot's lever and the carburettor throttle were at their maximum length, following which the pilot's lever would then pull directly on the throttle and close it. This period during which the throttle remains steady in spite of the closing of the pilot's lever is what is known as the "dead" period in the Boost Control and it has been eliminated with the introduction of the variable datum boost control.

If the control is set with the pilot's lever in full throttle position, by means of the screw adjustment at the end of the capsule spindle, to rated boost, and the pilot's lever pulled slightly back to another position and the screw adjustment re-set to a pressure below rated boost and so on down the scale, each different position of the pilot's

lever having another setting of the capsule spindle screw, naturally the boost pressure would be lowered each time this screw was adjusted. This would be varying the datum of the boost control with the pilot's lever opening.

In practice this is accomplished by means of a cam, in contact with the top of the capsule spindle, coupled to the pilot's lever so that when the lever is gradually closed the cam allows the capsules to extend, move bodily away from the servo motor, thus varying the datum and making it necessary for a lower pressure to be exerted on the capsules to let the valve come back and maintain the ports in the closed and sensitive position. In the normal type of boost control the datum is fixed because after adjusting the screw for the required boost pressure, the end of the capsule spindle is locked in position by a wired nut.

Location of Faults During Engine Running

1. Failure of an engine to start.
2. Ignition.
3. Lubrication.
4. Carburation and distribution.
5. Overheating and/or loss of power.
6. Rough running and vibration.

1. Failure of an Engine to Start. This may be due to any of the following—

(*a*) *Carburettor Jets or Filters Choked with Dirt, Oil or Water.* In such cases it will be necessary to clean thoroughly the float chamber, pipe lines, and possibly the fuel tanks. Water may be present either in the fuel itself, or may accumulate as a result of condensation from the atmosphere. Dirt may include small particles of shellac used as jointing material, or small flakes of boiled oil from the inside of the float chamber or cored passages left after the doping process normally carried out to safeguard against porosity. Oil may accumulate when fuel pumps are fitted if serious leakage occurs at the glands, because this oil is conveyed through the relief valve back to the fuel tank.

(*b*) *Air Locks in Fuel Pipe Lines.* This may be due to leakage at unions, cocks and fitters, or the length and lay-out of pipe lines may be unsatisfactory.

(*c*) *Incorrect Doping or Priming.* If an incorrect mixture is supplied to the cylinders when doping prior to starting, difficulty may be experienced. This is more likely to happen with a hot engine. A weak mixture may be due to a defective doping pump or choked nipples. A rich mixture may be due to a flooding carburettor. See item (*b*), Section 4. It is better to under-prime, but if the cylinders have been inadvertently over-primed they can be cleared as follows—

(i) Make sure that the hand starter is out of engagement.

(ii) Make sure that the magnetos are earthed.

(iii) If the engine has been running, leave it a few minutes to cool off.

(iv) Turn the airscrew backwards several times with the carburettor throttle full open.

In hot weather the magnetos should be connected each to one of the two brush connections on the hand starter magneto, in order that both sparking plugs in each cylinder can be made to fire.

Do not switch on main magnetos until all cylinders are firing on the hand-starter magneto, if it can be avoided. If the engine tends to fire, do not try and produce a start by sudden opening of the throttle, because the accelerator pump will discharge fuel and may cause a fire in the air intake.

(*d*) *Faulty Magneto.* See item (*b*), Section 2. In addition the ignition may be timed incorrectly or on the wrong stroke. The timing of magnetos is dealt with on page 74.

The rocker arm of the contact breaker may be stuck on its pivot. This should then be removed, cleaned and replaced.

(*e*) *Failure of the Impulse Starter.* It is not unusual for the toggle mechanism to cease to function if it becomes clogged with oil and dirt. The remedy is to dismantle and thoroughly clean the parts before re-assembly.

(*f*) *Faulty Sparking Plugs.* (See item (*a*), Section 2.) If the engine has been standing for some days it is possible that the sparking plug insulators may become damp owing to condensation; in such cases they should be removed and thoroughly dried.

(*g*) *Earthing Leads or Switches Defective.* This may result in a magneto being intermittently or permanently earthed. The starter magneto may be defective.

(*h*) *Faulty Ignition Leads.* If braided ignition leads become soaked with water—in particular sea-water—they will cease to function satisfactorily. If the leads are crossed or insecurely fitted to the distributor cover, trouble will also be experienced.

(*i*) When an electric starter is used, it is possible that the accumulator may be nearly run down, and the speed of the crankshaft may be insufficient for the engine to start. In cold weather, oil is very much less fluid, and the speed of rotation will be further reduced. It is then advisable to heat the oil beforehand.

(*j*) *Faulty Gas Starter Valve.* When using a gas starter, one or more of the valves in the cylinders may be faulty; or a gas starter pipe may be blocked or cracked. If the gas starter valves are not in regular use there is a tendency for the hole to be entirely blocked up with carbon. It is possible also for carbon to get under the seat of a valve, in which case the leakage of hot gases will soon weaken the spring, when burning of the valve seat must, of necessity, follow. It is important, therefore, to see that these valves are kept in perfect condition.

(*k*) *Incorrect Timing of Ignition.* On some types of engine the failure of the hand-starting mechanism to properly disengage after the engine has been started may result in the auxiliary drive shaft being permanently twisted. In such cases the ignition timing will be affected and severe backfires may occur on subsequent attempts to start the engine.

(*l*) *Loss of Compression,* due to worn or weak gas rings, leaking valves or loose inserts, dirty lubricating oil with no "body" in it.

(*m*) If an electric motor is part of the starter, the brush gear may be worn or there may be an excess of oil.

If a starter battery is used, this may be run down or in a deteriorated condition.

2. Ignition. Faults with an ignition system may be due to any of the following—

(*a*) *Sparking Plugs.* Unsatisfactory functioning of a sparking plug may be caused by—

(i) Faulty, loose, or cracked insulator. With mica insulators, pin holes may be present, also deposits of lead from the fuel may occur. In both cases electrical leakage may result.

(ii) Burnt, oily or dirty electrodes. Burning of the electrodes indicates pre-ignition or severe overheating, whilst dirty electrodes will cause a loss of power and make engine starting more difficult. Burning and oiling up of points may also occur if the wrong type of sparking plug is used.

(iii) Incorrect gap setting. The gap between the points should never be corrected by adjusting the central electrode with the sparking plug assembled. When the gland nut is slacked off the central electrode should be turned round to obtain the correct gap, which will be checked with narrow feelers.

(iv) Leakage between the gland nut and the central electrode.

Note. In each case it will be necessary to dismantle the sparking plug to clean and adjust. On re-assembly test each sparking plug for satisfactory functioning under a pressure of 100 lb. per sq. in.

(*b*) *Magneto.* Unsatisfactory functioning of a magneto may be due to any of the following—

(i) Dirty, damp, or cracked distributor.

(ii) Pitted or worn contacts. This will necessitate either the renewal of parts, or trimming up the surfaces, leaving them smooth and preferably slightly convex. The latter can be done in a lathe. Alternatively, if a file is used it should be a very fine one, and every care should be exercised.

(iii) Bad contact between the primary lead and the contact breaker pillar, or the insulation of the contact breaker may be defective. Dirt can easily be responsible for leakage.

(iv) Sticking of rocker arm, or wear on its pivot, thus preventing satisfactory "make" and "break."

(v) Contact breaker rocker arm spring corrosion, indicating pending failure. This is dealt with in Notice to Aircraft Owners and Ground Engineers No. 26, of 1934, and a protective treatment is indicated.

(vi) Broken carbon brush. This should be renewed after thoroughly cleaning the track. It is undesirable to attempt to rectify the face of a carbon brush.

(vii) Faulty condenser. This is usually indicated by a white deposit on the contacts.

(viii) Weak spark from a magneto. This suggests that the magneto either requires overhauling or the magnets require re-magnetizing.

If storage conditions are such that dampness may be suspected, the magnetos should be placed in a warm place and dried off.

(ix) If an impulse starter is incorporated this may fail to operate due to its dirty condition, or as a result of wear of the parts. The questions of lubrication and wear are dealt with in Notices to Aircraft Owners and Ground Engineers, Nos. 27, of 1934 and 10 of 1936.

(c) *Ignition Leads.* Unsatisfactory functioning of an engine may be associated with the condition of the ignition leads, and the following points may be mentioned—

(i) A breakdown of the insulation may cause a partial or complete "short." This may happen if the rubber becomes cracked or perished or the cambric or metal brading deteriorated. Oil and heat have detrimental effects on rubber, and for these reasons the leads should be securely attached so that they are quite clear of parts that become very hot. Severe bends and over-tightening of clips are undesirable, and leads should not be allowed to rub against nuts, sharp edges, etc., or fretting will soon occur as the result of engine running.

(ii) A bad contact or connection in the socket of the distributor cover may cause intermittent firing of the plug in the cylinder corresponding to the faulty lead.

3. Lubrication. Trouble with lubrication may be experienced under any of the following headings—

(a) *Low or Fluctuating Oil Pressure.* This may be due to any of the following causes—

(i) Shortage of oil in the sump or tank.

(ii) Air leaks in the suction pipe to the oil pump. All unions should be tight.

(iii) Relief valve incorrectly set or stuck up due to dirt under its seating.

(iv) Faulty pump. Efficiency of a gear pump will be seriously impaired if the walls have been scored badly with dirt, sand, etc., or if the gear teeth have worn to such an extent that excessive back lash results.

(v) Worn connecting rod bearings. The diametrical clearance and end float of bearings on their crank-pins control, to a great extent, the pressure of the oil, particularly on engines where the capacity of the oil pump is normally only just sufficient for the engine.

(vi) Leaking crankpin plugs. This trouble is not uncommon, and can only be prevented by carefully lapping in all plugs at engine overhaul followed by an appropriate pressure test.

(vii) Defective pressure gauge or possibly a blockage in the pipe leading to the gauge. In cold weather the oil in the pipe may become rather thick, and as a result the true pressure will not at first be recorded. Further delay may occur if the pump and system have not been primed.

(b) *High Oil Pressure.* This may be due to any of the following causes—

(i) The relief valve may be sticking due to dirt. If an auxiliary

relief valve is fitted inside the crankcase and functioning does not occur regularly, there is a risk of the valve becoming blocked due to congealed oil.

(ii) The relief valve may be adjusted incorrectly. If a spring of incorrect length or gauge of wire is fitted the blow-off pressure will be incorrect.

(iii) The pressure filter may be choked with dirt and carbon.

(iv) The pressure gauge may be defective. It will be appreciated that when starting up an engine, the oil will be cold and sluggish, and pressures recorded will be higher than when the oil is hot.

(*c*) *High Oil Consumption.* This may be due to any of the following—

(i) Oil passing piston and scraper rings due to excessive gaps or unsatisfactory ring surfaces. It can be detected on the test bench if stub pipes are fitted for the tests, by a careful examination of the exhaust.

(ii) Oil leakage from breathers. This may be due to the breathers not functioning satisfactorily, or to overheating causing an excess of oil mist to leave the breather as a result of increased crankcase pressure.

(iii) Leakage at tappet guides, etc.

(iv) Leakage from spring loaded oil gland on impellor spindle due to faulty bedding of face, weak or broken springs or sticking gland.

(v) High oil temperatures and pressures.

(vi) Faulty scavenging due to leakage on suction side of scavenge pump or faulty pump.

(vii) Leakage from pipe line unions.

(viii) Faulty measuring apparatus, or aeriation of oil, thus giving unreliable measurement.

(*d*) *Low Oil Consumption.* This may be due to any of the following—

(i) See item (*c*) (viii) above.

(ii) The oil consumption reading may be misleading if the whole of the oil in circulation is not warmed up. For this reason no reading should be taken for, say, 10 minutes after the engine has run at 9/10ths load.

(iii) With some engines the master rod bearings act to an important extent as oil metering devices, in that if the diametrical clearances and end float are too small, the cylinder walls may not be adequately lubricated, and low oil consumption will be recorded.

Whilst this point should not be overlooked, it should be remembered that it is well to pass engines out with oil consumptions as near as possible to the low limit of the rating.

(*e*) *Suitability of Oil.* It should be quite clear that brands of oil inferior to, or different from, those approved for a particular type of engine must not be used. Many oils may appear to function satisfactorily during a short run on the test bench, but may be entirely unsuitable for a particular set of conditions over a long period of

service in the aircraft. Thus, an oil suitable for cold climates may be quite unsuitable for hot ones, and it is to be expected that high oil consumption, ring gumming and similar troubles, will be experienced if the wrong oil is used.

4. CARBURATION AND DISTRIBUTION. *Note.* The tuning of an engine should be done when it is warm, and the correctness of the distribution may be checked by the colour of the exhaust flame when running with stub pipes fitted at 9/10ths power. (See page 82 for further particulars.) If the mixture control is gradually opened up and the engine revolutions increase, this is an indication that the mixture was initially too rich; conversely, if the revolutions drop as the mixture control is opened, an initially weak mixture is indicated. The actual fuel consumption should be checked on a flowmeter.

Flame traps are incorporated in the induction pipes of some engines to obviate any tendency to cut out due to weak mixtures, inlet valve leakage, etc. In addition, atomization of the fuel is also improved.

A flame trap may comprise a pad or roll of corrugated metallic strip which fills the whole of the induction passage.

Unsatisfactory distribution may be due to any of the following—

(*a*) *Choked Carburettor Jets or Filters.* (See item (*a*), Section 1.)

(*b*) *Carburettor Flooding.* Erratic functioning of the float mechanism may easily affect the correctness of the mixture, and the following are contributory causes—

(i) Wear of the needle, needle valve seating or dirt preventing the needle from seating properly. Parts should be renewed if any defect is noted and needles may be lightly lapped into the valve seatings, using metal polish as a lapping medium.

(ii) Pin missing from a toggle, or sticking needle.

(iii) Punctured float, or in the case of a cork float, punctured varnished coating which would permit fuel to enter the cork.

In the case of a metal float it should be immersed in hot water; the fuel will evaporate and the leak can be traced. After all fuel has been expelled the hole can be soldered up.

With cork floats there is a risk of some protective coating being attacked if fuels containing alcohol are used, in which case blisters will appear and peeling commence. The cork is soft on the surface and will eventually become fuel logged. Re-surfacing a cork float is difficult owing to the number of coatings that have to be applied. Special cellulose varnish must be used.

(iv) Level of fuel in float chamber too low. This may result in misfiring or cutting out of the engine on opening up and climb.

Level of fuel in float chamber too high. This can be checked by substituting the base plug for one with a pipe incorporated. A glass tube is connected to this pipe by means of rubber tubing. The level of the fuel in the float chamber when under the stipulated head, usually 6 ft., can then be ascertained. On replacing the base. plug care should be taken to see that same is locked.

(*c*) *Jet Sizes Incorrect.* An examination should also be made for loose or damaged jets and diffusers.

(*d*) *Loss of Compression.* If the compression varies on one or more

cylinders trouble may be expected. A method of testing compression where it is not convenient to try each cylinder in turn by turning the airscrew has been adopted by some operating companies, and is carried out as follows—

A sparking plug body is fitted with a piece of copper tubing, the end of which is bell-mouthed to accommodate an ordinary cork. This is fitted to each cylinder in turn, one plug in the other cylinders being removed.

The engine is turned slowly by means of the hand starter, and if the compression is satisfactory the cork should be forced out. The test should preferably be done whilst the engine is warm. If the cork remains in position it is probable that any of the following troubles may be present—

Valves not seating satisfactorily.
Gas starter valve leaking.
Piston ring broken or stuck in its groove.
Faulty cylinder head joint.

(e) *Air Leaks.* These are the main cause of weak mixtures, and on certain types of engine can be readily detected by the smoke test referred to on page 82. Leakage of air may occur from any of the induction joints, which should be checked individually for condition and tightness of nuts. Worn inlet valve stems and their guides and particles of grit under the inlet valve seats are also sources of air leakage.

Mixtures of the order of 65 per cent of the correct mixture strength and below will result in the failure of an engine to fire. Weak mixtures result in a slow rate of flame propagation, and the exhaust products are still at a high temperature when the inlet valve opens to admit a fresh charge, the ignition of which causes a flame to pass into the induction system with the familiar "pop back."

(*f*) Carburettors in which the main body comprises two portions, normally incorporate some form of joint. In many carburettors the functioning of the pressure balance and mixture control systems depends on maintaining air pressure or depression above the fuel in the float chamber, and for this reason care must be taken when making this joint to see that the faces are scrupulously clean and free from air leaks.

(*g*) If more than one carburettor is fitted to an engine the throttles, mixture controls, and power jets should be carefully synchronized so that the operations in each carburettor are effected simultaneously. The same remarks apply to carburettors incorporating more than one throttle.

(*h*) If diaphragm petrol pumps are fitted the diaphragms may become split or punctured, in which case recalibration on a rig, after replacement, becomes necessary. Alternatively, if an incorrectly adjusted pump is fitted, flooding of the carburettor may occur. The relief valve spring loading may vary with different installations.

(*i*) If testing is carried out with the air intake in the slip stream from the test fan, propeller, or air flow from the brake fan, the distribution will be upset. Similarly, if the air intake is non-standard,

or if flame traps or air filters are incorporated, the results with standard jets may easily be unsatisfactory.

(*j*) Erratic distribution may be caused if the air vent of the filter cap of the tank or the vent pipe are stopped up.

Slow Running. This can easily be affected by most of the causes enumerated in Section 4. In addition, the following points are brought to your notice—

(*a*) The butterfly of the throttle may not close fully, or if more than one throttle is incorporated in a carburettor, they may not be quite synchronized.

(*b*) Slow running jet may be out of adjustment, and where a quantity screw is incorporated this may be set incorrectly.

(*c*) Where face glands are incorporated on impellor spindles to effect a seal between the crankcase and impellor casing, leakage of air might occur due to the gland lifting as the result of suction at slow engine speeds counteracting the spring loading on the gland.

(*d*) *Broken or Weak Valve Springs.* The former must be changed. The latter, if more than one is fitted to a valve, can sometimes be selected as a temporary measure, to give a satisfactory combined loading.

5. Over-heating and/or Loss of Power. These conditions may be attributable to any of the following—

(*a*) *Rich and Weak Mixtures.* (See Section 1, items (*a*) to (*c*).)

(*b*) *Detonation.* This may be caused by—

(i) The use of an unsuitable fuel, that is to say one inferior to that approved on the Type Engine.

(ii) The ignition timing advanced too far.

(iii) The compression ratio too high. See page 73 for further particulars.

(*c*) *Pre-ignition.* This may be due to—

(i) Overheated sparking plug points.

(ii) Incandescent carbon on the piston crown and valves.

(iii) Sharp edges, such as a burred screwdriver slot, often provided on the valve head, which may become red hot.

Note. The above can be accelerated by insufficient cylinder cooling due to a faulty airspeed indicator, omission of cylinder baffles, if normally fitted, and excessive oil inlet temperatures.

(*d*) *Ignition Timing.* If the ignition is retarded this will cause overheating, but an advance in the ignition normally permits weaker mixtures to be used.

(*e*) *A Dirty Engine*, that is to say, one that requires top-overhauling or decarbonizing. It may also have weak compression on some cylinders owing to the valve condition, and will certainly be down in power.

(*f*) *Dirty Sparking Plugs.* (See Section 2, item (*a*).) A loss of power will result from dirty sparking plugs.

(*g*) *The Cooling System.* On water-cooled engines the cooling system may be unsatisfactory in regard to the following—

(i) Insufficient radiator surface, or insufficient cooling due to deposits and dirt.

(ii) Water leaks from rubber joints, cocks, pipe lines and pump gland.

(iii) Faulty water pump, due to corrosion, etc., causing loss of efficiency in circulation of the water, particularly at speeds below normal.

(iv) Air leaks in the water system or steam pockets in the cylinders.

(*h*) If the water jackets of cylinders are "furred" up with deposit thrown out of the water, overheating may occur. If such is the case deposit should be removed as already described on page 56. It is always advisable to use distilled or rain-water for cylinder cooling.

(*i*) *Silencing.* Manifolds creating excessive back pressure will cause loss of power and overheating on some cylinders.

(*j*) Airscrew test fans providing an air speed of less than 80 miles an hour are likely to permit an engine to overheat if run for long periods at large throttle openings.

(*k*) With a supercharged engine the failure to get rated boost may be due to a slipping clutch.

(*l*) *Faulty Boost Control—*

(i) Ensure that the oil pipe line to, and the return pipe from, the boost control unit are quite clear of obstruction Failure of the oil. pressure means failure of the boost control, and a stop is provided on the piston as a safeguard.

(ii) The oil hole in the piston of the unit should be clear, otherwise surging may occur.

(iii) All pressure and depression pipes to the unit must have unions tight, and pipes must be free from cracks.

(iv) If a boost gauge is used to measure boost pressures, it should be checked daily against the standard barometer.

(v) A punctured capsule will cause failure of the boost control. Capsules may fail due to rough handling, excessive engine vibration. etc.

(vi) Hunting or variable boost may be due to worn linkage mechanism, worn or slack sleeve controlling piston ports, capsules with incorrect expansion rate under temperature and pressure changes, incorrect leak hole in piston, etc.

A change of pressure of $\frac{1}{8}$ lb. per sq. in. should cause the piston to move, and accuracy within $\pm \frac{1}{8}$ lb. per sq. in. may be expected.

(vii) With air-operated boost controls, grit may score the cylinders and cause fluctuation.

(viii) Tight or dirty piston valves will cause sluggish operation and possibly a low boost reading at rated boost position. The valve should be removed, lapped with metal polish, washed and replaced.

6. Rough Running and/or Vibration. These may be caused by any of the following—

(*a*) See Section 1, items (*b*), (*g*) and (*j*) and Sections 4 and 5.

(*b*) *Dirty or Incorrectly Adjusted Sparking Plug Points.* See Section 2, item (*a*). *Note.* After a run a faulty plug can usually be found, because it will be considerably cooler than the others.

(*c*) *Clearance of Valves.* These may be out of adjustment.

(*d*) *Valves or Tappets Sticking.* This may be due to bent stems in

the case of valves, and if over-heating has occurred scaling of the stem may also result in a valve sticking in its guide. After rectification or renewal the valve stem should be smeared with high melting point grease and graphite before fitting.

(e) *Broken or Weak Valve Springs.* The former will occur if the spring is not seating flat and square. Similarly springs may give trouble if used on an engine of similar type but later series, because critical speeds may arise which produce "surging," or the engine may be fitted with high lift camshafts which would also impose additional stresses. Springs are often enamelled different colours to denote class of material or other limiting features.

(f) *Excessive Back-lash of Reduction Gear Teeth,* or engine parts out of balance. This latter point becomes particularly important with Rotary Engines.

(g) *Faulty Magneto,* or magnetos not properly synchronized. See Section 2, item (b). A faulty magneto can be detected by effecting a check on each magneto separately and noting the drop in airscrew revolutions. If the drops exceed those normally noted on the port and starboard magnetos respectively, a faulty ignition system may be expected. If no drop occurs it may be assumed that the ignition timing is advanced too far.

(h) *Test Bench.* The following faults may contribute to erratic running—

(i) The engine mounting too flexible.

(ii) The foundations of the test house floating.

(iii) The alignment of the engine with the brake shaft incorrect.

(iv) Hunting may occur due to incorrect adjustment of the dashpot or fluctuating water pressure.

(v) Loose or unsuitable coupling between engine and brake shaft.

(vi) If an airscrew test fan is used it may be out of balance, or the hub may be loose on the airscrew shaft.

Note. When tuning an engine overheating may occur if it is run for some time at large throttle openings, and if suddenly switched off explosions may occur due to the high temperature of sparking plugs, valves, etc. For this reason stopping an engine should be carried out as follows—

(i) Run the engine for a little while at its minimum speed so that engine has time to cool off.

(ii) Turn off fuel and when firing has ceased switch off magnetos.

SLEEVE VALVE PETROL ENGINES. Aero-engines in production featuring sleeve instead of poppet valves are in the main of the air-cooled radial type and operate on the four-stroke cycle; in consequence, parts which differ materially from established practice for poppet valve engines are those associated with the cylinder.

Each sleeve receives its motion through a crank, operated at half engine speed by means of a train of spur gears driven from the crankshaft. The sleeve normally receives both reciprocating and partial rotating motions, resulting in an elliptical path during its cycle.

Ports are provided in the cylinder barrel walls with corresponding ones in the nitrided sleeves. During one cycle of operations the inlet

and exhaust ports are gradually uncovered in correct sequence, permitting a fresh mixture to be admitted and the burnt charge to be exhausted. The valve timing is set by observation of the port openings.

A junk head, bolted to the top of the cylinder barrel, accommodates the over-ride of the sleeve, sealing being effected by piston rings. A sealing ring may also be provided outside the sleeve at the bottom end. Sparking plugs are accommodated in the centre of the well of the junk head and require special consideration to secure the maximum cooling, which is done by deflecting air into the well, in addition to the provision of as much finning as possible.

The following features are in favour of sleeve valve engines when compared with the poppet valve types.

(*a*) The port opening and closing characteristics combined with clean combustion head design and central sparking plug position provide higher volumetric efficiency, improved scavenging, and consequently reduced fuel consumption. The thermal efficiency is better and the exhaust gas temperature lower.

(*b*) Maintenance is easy owing to the elimination of valves, valve springs, cam mechanism, drives, etc., but additional parts are necessary to operate the sleeves, including cranks and driving gears.

(*c*) Mechanical noise is reduced.

(*d*) Trouble often associated with valve seating inserts is entirely eliminated.

Reliability is no better than other types of engine incorporating poppet valves and springs. Starting is more difficult, particularly if sleeves are dry or cold. Increased turning speed is necessary.

Compression Ignition Engines

This type of engine has already reached a state of development when it has taken aircraft into the air, and a short time only is likely to elapse before they are in a state of production. It is natural, then, that if a ground engineer wishes to obtain a licence for a compression ignition engine at the present moment, he would be expected to have a thorough knowledge and experience of the particular type. Speaking generally, compression ignition engines differ from petrol engines only in so far as combustion and ignition systems are concerned, the carburettor being superseded by one or more fuel pump units, whilst the magnetos and sparking plugs are dispensed with altogether. The two-stroke principle of engine operation as well as the four-stroke "Otto" cycle will be met with in certain types of compression ignition engine.

When comparing the performance of compression ignition engines with petrol engines, a number of differences will at once be apparent and your attention is drawn to the more important of these.

(i) The C.I. engine has a high thermal efficiency at all loads and consequently there is less heat rejected to the water jackets in the case of liquid-cooled types, and to the surrounding air in the case of air-cooled types.

(ii) The C.I. engine has a high ratio of maximum to mean cylinder pressure, and the construction is accordingly slightly more robust than the petrol engine.

(iii) The specific fuel consumption is much less than that of a petrol engine and the weight of fuel to be carried for long flights represents a big saving over that for a petrol engine.

(iv) Pure air only is aspirated and if a supercharger is incorporated the same quality of fuel is used. There is more scope for the development of the two-stroke principle when only pure air is drawn into the combustion chamber.

(v) The tendency of the C.I. engine to detonate compared with the supercharged petrol engine, is very much reduced because in the former case the fuel is injected near the end of the compression stroke.

(vi) The fuel used in C.I. engines is much less volatile at low temperatures than petrol and danger from fire is much reduced.

(vii) The absence of electric ignition eliminates one of the main causes of wireless interference.

It will be found that high compression ratios are made use of, and special attention must be given to clearances affecting the combustion chamber. Valves and piston rings must receive careful attention for the same reason.

It will be seen from the foregoing remarks that a ground engineer familiar only with petrol-driven aero-engines, will have to become conversant with the functioning and adjustment of the fuel pumps peculiar to compression ignition engines, and the various atomizers which spray the fuel into the combustion chamber. Normally, the fuel is injected towards the end of the compression stroke, and the charge in the combustion chamber is ignited as the result of the heat generated during the compression stroke. The arrangement for mixing the air and fuel varies according to the type of engine and design of the combustion head.

The fuel pumps measure the amount of fuel, which varies according to the load on the engine, and deliver it at high pressure to the atomizers. The pumps, which constitute part of the engine, are usually of the plunger type. Gear type booster pumps are sometimes fitted to supply fuel from the tank at a pressure to the main pumps, a relief valve being incorporated in the system.

The fuel pumps may be arranged in blocks embodying a number of them, or each pump may be a separate unit, and it should be clear that in either case a pump is required for each cylinder, and a calibration of the fuel delivery from each pump has to be made separately. The pumps are usually controlled as regards the quantity of fuel and period of injection by means of a plunger type control valve. This is very important, as it has a direct bearing on the cylinder pressures obtained during the ignition of the mixture.

The fuel valve, or atomizer, usually comprises a valve with a spring that lifts at a high pressure, normally well in excess of 1000 lb. per sq. in., and allows fuel to pass through one or more small holes into the combustion chamber. The fuel is specially filtered before passing to the atomizer valve. The valve must be a perfect fit on its seating, and on being tested the fuel should pass at a definite pressure obtained by adjustment of the spring. When the pressure is released the fuel should cut off definitely without dribble. It is important to keep clear

of the jets of fuel when testing. There is normally an external leakage of fuel from the atomizer, and this is carried away by a pipe.

The ground engineer will also have to be familiar with any supplementary system which may be embodied to facilitate starting, and it is usual in this connection to incorporate a decompressor which operates on the exhaust valves. In addition provision is normally made to retard the period of injection to prevent excessive cylinder pressures.

It is of the utmost importance that the maximum permissible cylinder pressures shall not be exceeded, and for this reason the normal test bed equipment must be augmented by some form of apparatus for recording cylinder pressures. One such piece of apparatus includes a disc valve unit, an air bottle, and a pressure gauge. A passage from the cylinder to be measured is connected to one side of the disc, whilst a pipe from the air bottle is connected through a regulating valve to the other side. The disc has a limited movement, and when on its seating is insulated electrically from the body of the unit.

The regulating valve from the air bottle is gradually opened until the pressure each side of the disc valve is balanced. When this occurs the disc acts as a "make and break" of a primary electrical circuit, and induces a high potential spark in the secondary circuit. This spark is arranged to jump a gap between the end of the pointer of the pressure gauge, and the outside of its case. Readings should be taken of pressures corresponding to intermittent sparking as well as regular sparking.

It is believed that a schedule of tests for acceptance of compression ignition engines after overhaul is in draft form, and will be issued in due course as Design Leaflet No. C6 (A.P. 1208).

Power Units

The difficulty in effecting major adjustments to modern aircraft engines is to a great extent overcome, if it is possible to change the power unit complete, when it could be sent to a fully equipped workshop for attention. With this in mind, many modern aircraft have self-contained power plants, attached by four or more easily detachable connections. This arrangement would make it possible to adapt one type of power unit to several types of aircraft, with only minor alterations.

A power unit may include the fireproof bulk head in certain installations, but would not include the fuel and oil tanks. The power unit would include the engine and its mounting with or without additional superstructure, accessories either on the engine or fitted to a separate shaft-driven gear box, exhaust manifolds or ring in the case of a radial engine, oil radiator, cowling, air intakes, etc., and with a liquid cooled power unit, header tank, thermostats and coolant radiators. Accessories, radiators, thermostats, generators, etc., would normally be supplied with a clear inspection release from the various sub-contractors, covering manufacture, the safeguarding of interchangeability points, etc.

The following controls, accessories and services would normally have to be connected after fitting a power unit to an aircraft: Fuel and oil supply pipes, throttle and other carburettor controls, hot and

cold air flap, lever of control unit operating the C.P. airscrew, leads for the generator and starter motor, pipes to oil and boost gauges, drive for revolution indicator, capillary tubing from header tank thermometer, air pump pipes, priming pipe, control rod operating flaps on radial engine cowls, etc.

The weight of a complete power unit must be maintained within specified limits, otherwise the centre of gravity of the aircraft might be affected. In the following notes on the various phases of power unit construction, new manufacture has been cited, but the procedure is identical for repair work, which should, after completion, be as reliable and to the same standard as new work.

The inspection of engine mountings, cowlings, radiators, header tanks, and their installation would normally be made by a "B" licensed ground engineer, but with the introduction of power units, which are normally designed, manufactured and repaired by the engine makers, the bulk of responsibility may have to be carried by the "D" licensed ground engineer.

Engine Mountings. These are normally constructed of steel tubing, welded together in the case of small aircraft, but built up in conjunction with machined steel forgings in the case of larger and faster aircraft. Acetylene welding is normally employed, but a limited use has been made, with Air Ministry consent, of electric welding. The forgings are secured to the tubes either by welding, riveting, or high tensile steel bolts. The weight of the forgings must be carefully controlled and, consequently, they are normally machined all over to close dimensions and with very good finish. With the more elaborate fittings, where a number of tubes have to be located about one centre, inspection tackle has to be provided to secure the necessary accuracy. Holes are drilled near the bottom of each socket or spigot as witnesses that the tubes are sufficiently far over or into their locations.

The tubes are cut to length, but drilling for rivets or bolts can only be effected after assembly of the components on a rigid jig. The fit of the bolts must be perfect, and it is sometimes necessary to pass a reamer through to secure the required fit. Slackness of the structure not only promotes fatigue failures, but there is also a risk of engine vibration. After drilling, the tubes are removed from their locations in order that all burrs may be eliminated and all swarf removed. Before reassembly, the tubes are treated internally with anti-corrosion protection and the bolts are smeared with an anti-corrosion paste.

The complete structure must, of course, conform dimensionally with the limits on the approved drawings, and to ensure this it is necessary to fit up and erect the component parts on a rigid jig incorporating positioning points for attachment lugs, engine bearer feet or engine support ring in the case of a radial type engine, cowling rails, radiators, etc. The usual method is to insert ground pins at the various points, the sizes corresponding with the fixing bolts used at each position when components are attached.

The complete structure is protected externally either by cadmium plating, stove enamelling, sprayed paint or other approved process. With the plating process it is necessary to carry out a low temperature

embrittlement treatment afterwards. Whatever the finish, it is desirable that the inspection and identification markings on the component parts shall be discernible, as this would facilitate replacement if, for any reason, damage necessitated their renewal. In view of this, it is not considered that etching would be effective.

With multi-cylinder engines other than radial types, two half mountings, left and right-hand respectively, sometimes form a complete structure when assembled to the engine, and consequently shimming under the bearer feet may have to be introduced to obtain the accuracy required for the pick-up points on the aircraft. Mountings are usually built with a slight plus inclination to accommodate any sag resulting from the weight of the engine and accessories. This may be as much as 10 minutes when tested with a clinometer on the top of the airscrew shaft. A further sag will occur after the power unit has been assembled to the bulk-head of the aircraft, and in consequence the short fuel and oil pipes which have to pass through the bulkhead are usually of flexible tubing.

The power unit attachments may be of the ball and socket type with a nut to retain the ball end in the socket, or the ordinary fork end type of fastening may be used, in which case tapered bolts are preferable if back lash is to be entirely eliminated.

Any form of bad landing imposes a considerable strain on the engine mounting and if the airscrew hits an obstacle it is certain to impose some strain on the structure. For these reasons power units that come in for repair require the most careful inspection after they have been completely stripped down and all paint, dirt, etc., have been removed. Bent tubes are the first consideration and should be discarded. Tubes with signs of rusting or pitting, either inside or outside, must be considered on their merits. Each part should be subjected to magnetic test for the presence of cracks or seams. All welded joints should be examined to see that they are sound.

The reduction gear of the engine would have to be inspected and with "inline" or "v" engines, the bearer feet would be examined for cracks.

Installation of the Engine and its Accessories. In order to receive the engine, the mounting is erected on a dummy bulkhead incorporating pick-up points conforming strictly to those of the aircraft. It must be aligned with the specified plus inclination and all interchangeability points must be correct to the templates provided for this purpose.

The engine is removed from its packing case or stand by means of the lifting eyes normally provided for the lifting tackle. Every care must be exercised to make sure that the engine does not swing and damage protruding parts or accessories. This is even more important when lowering the engine on to the mounting, and at no time must it be allowed to rest partly or wholly on its crankcase unless provision has been made for that specific purpose. When the engine is in position, the fit of the bearer feet on their platforms will be checked with feelers to ensure perfect contact. With radial type engines the bearer plate must be flat and the holding down bolts should be tight before the

weight of the engine is released from the lifting tackle. These bolts should be a good fit in the holes of the mounting ring and must be adequately locked.

If the power unit incorporates an independent accessory gear box, this will be assembled next as a complete unit with accessories already mounted. If the accessories are carried on the engine drives it may happen that to facilitate fitting the engine to its mounting, certain accessories have been left off. This will necessitate breaking the joint of the blanking plate to fit each accessory, and will require care to make sure that a sound joint is subsequently provided.

With liquid cooled engines, components of the coolant system will be fitted before assembling the numerous pipes and smaller details. The header tank is situated at the top of the engine, and if of the horseshoe type, that is to say, if it straddles the engine, care is required in tightening up the securing bolts to see that the tank is not distorted. Thermostats will be mounted on aluminium brackets, carefully aligned, as the run of the pipe work is largely controlled from them. The settings at which the thermostats control the coolant temperatures will be verified, but can only be confirmed after flight. The radiators will be assembled next, and these are often hung from the mounting by means of built-up welded fittings or aluminium alloy stampings. Some radiators are of a circular pattern, secured to brackets by steel straps. Even though suitable packing is inserted between the straps and the radiator, every care is required to make sure that no damage results from overtightening.

Oil radiators, starting mechanism, air intakes, fire extinguishing system, pipe work, manifolds, etc., have yet to be dealt with, and the order of fitting these items varies according to the type of engine. It always happens that during assembly, there are many openings which have been blanked up temporarily either by a carefully designed cap or something less permanent. The necessity for ensuring that orifices are perfectly clear when connecting up the pipe work cannot be too often stressed, and the use of pieces of rag is definitely dangerous.

FUEL SYSTEM. This will start from the bulkhead where a metal connection will be situated. The run of the pipe line to the fuel pump and then to the carburettor may incorporate a fuel pressure regulator such as the Amal reducing valve. This is normally fitted near the carburettor and at the same level as the float chamber. The pressure is maintained constant at a figure below that at which the carburettor would normally start flooding.

The pipes must be of correct bore, gauge, and material. Copper in the soft annealed condition is generally used, and bends are avoided as far as possible. To ensure interchangeability, lengths of pipe are made to templates, and whilst the installation drawings should provide for flexibility, adequate support at regular intervals is equally important. All fuel pipe lines should run quite clear of hot bodies, particularly exhaust pipes and manifolds, because air will separate from the fuel if the temperature rises above 50° C. when the risk of air locks is increased.

All unions shall be of an approved pattern and secured to the

tubing in an approved manner. Silver soldering is usually adopted, and care is required to see that no excess of solder is left inside the bore because a restricted fuel supply would cause erratic engine running. When silver soldering a copper pipe to a steel fitting, there is always a risk of burning the copper and forming copper oxide. The structure becomes coarse and crystalline, and under the microscope a number of small cracks may be noted. This condition would expedite the splitting of a pipe when subjected to the normal stressing during engine running.

The completed system should be tested for flow from the tank to the carburettor if it is a gravity feed installation, otherwise the system must be tested by an electrically-driven slave fuel pump. In either case the quantity of fuel passing in a given time must conform to the requirements laid down in the appropriate paragraphs of A.P. 1208, which stipulates that the fuel tank shall not be more than 10 per cent full of fuel and the system shall be at an angle to give the minimum head. These tests also show up any leaky joints or taps and serve to remove any foreign matter such as grit or solder. A further flow test inspection must be made after the engine has been run up on the ground. All unions must be locked with single soft copper or brass wire, which passes through a hole drilled through the corner of two flats of the hexagon and is then attached to any adjacent fixed part.

When flexible piping is used as part of the pipe line, there are several approved supplies such as Superflexit to Specification D.T.D. 1014, Petroflex to Specification 1009, although approval may be limited to certain types of aircraft. They are usually supplied fully released by the makers, to specified lengths with the ends fitted, because if the lining becomes damaged in the process of fitting the end connections, the petrol resistance is materially impaired. It is also essential that electrical contact must be made throughout the length of the pipe. Acute bends should be avoided.

Drain pipes for carrying away excess fuel from the air intake must be fitted, even though flame traps are incorporated somewhere in the induction system. They must carry the fuel outside the cowling and right away from any exhaust pipes or manifolds.

Lubrication System. The pipes to and from the oil radiator will normally connect to unions passing through the bulkhead of the aircraft, and similar fittings should be provided on the dummy bulkhead. The pipe lines should be as direct as possible and all unnecessary bends avoided as the flow of oil, particularly when cold, is sluggish. The throttles of modern carburettors rely on the hot oil to prevent them sticking, due to ice formation when the atmosphere is cold and damp. The oil also supplies some of the latent heat required to vaporize the fuel. Provision should be made for draining the system after a run, as it may be necessary on cold mornings to prime the system with hot oil.

The pipes are made from copper, aluminium, or tungum, of the appropriate bore and gauge, and templates are provided to ensure interchangeability as regards length and shape. This is important, because the pipes normally run close to the cowling panels and

adequate clearance must be provided to prevent contact which could otherwise arise from vibration, and distortion of the mounting under flying conditions.

Unions are secured to the pipes either by soldering or brazing. The solders and fluxes specified on the drawings must be adhered to. The pipes, when full of oil, are heavy and particular care must be taken to adequately support them and to see that they do not rub any other part of the installation. Small pipes can normally be formed on a bending machine but the larger ones, particularly if thin walled, must be filled before bending. Fillers such as sand, lead, and resin have been used, but the present practice is to use a low-melting temperature alloy such as Wood's metal. Where this is permitted the following points should be noted—

(*a*) To prevent the filler sticking to the inside of the tube a film of oil is applied before filling.

(*b*) One end of the tube is stopped up and the whole preheated in boiling water before pouring in the filler, which melts below 100° C. The whole is then quenched. With light-Al alloy tubes the period of immersion in boiling water should be as short as possible, otherwise there might be a tendency to accelerate age hardening.

(*c*) The tube is then bent to the correct form.

(*d*) After removing the filler by submersion in boiling water, the inside of the tube is cleaned by means of a pull through whilst it is still at a temperature above the melting point of the filler.

Starting System. With hand starting the shaft will probably drive a starter magneto by means of cycle chain and sprockets providing about 12 to 1 upward ratio. A spring-loaded jockey sprocket is fitted to take up any chain slackness. This will be mounted on a bracket which should be securely fixed to a tube of the mounting. The clutch loading is set in the works for normal conditions of operation. Slipping may occur in cold weather when clutch adjustment would have to be made. Electric starting necessitates a booster coil and a double starter switch. When the switch is depressed the motor which turns the engine is engaged, whilst further depression of the switch makes contact with the booster coil which provides a spark in one of the cylinders.

Accumulators are subjected to very heavy loads on starting an engine, possibly 100 amperes for 30 seconds, consequently regular and careful servicing is essential. Attention to the S.G. of the electrolite, topping up with distilled water, vaseline on the terminals, etc., are routine matters.

If the cables between the accumulator and starter motor are long, such conditions arising when starting with a ground battery, a heavy voltage drop must be expected unless the cables are heavy. The contacts must be clean and tight. The brushes of the motor and the dynamo must be clean and the springs in good order.

Copper priming pipes should be provided with coils, made horizontally, to safeguard them against vibration. When operating the priming system, non-return valves are normally incorporated. These must be kept clean and free of dirt. Cocks are also provided in many

systems, and it is important that they shall all be pressure-tight and cannot come undone by vibration. Periodical inspection for marine atmospheric corrosion is desirable if an aircraft has been operating near the sea.

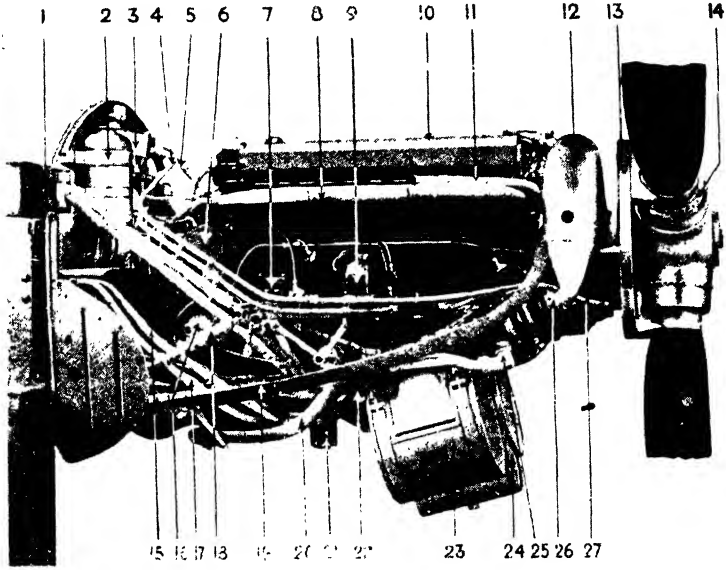


PLATE XXI. A LIQUID-COOLED POWER UNIT WITH COWLING PANELS REMOVED

1. Power unit attachment bracket.
2. Oil filter casing.
3. Air and oil separator.
4. Pipe from vacuum pump.
5. Petrol priming pipe.
6. Starboard magneto.
7. Rear starboard engine bearer foot.
8. Streamline built up exhaust manifold.
9. Hand-starting magneto.
10. Air vent.
11. Crankcase breather pipe.
12. Coolant header tank.
13. Front cowling ring.
14. Controllable pitch airscrew.
15. Pipe to oil radiator.
16. Hand-starter shaft.
17. Pipe from oil radiator.
18. Engine mounting.
19. Main side cowling rail.
20. Coolant pipe from pump.
21. Retractable undercarriage pump.
22. Coolant pipe to pump.
23. Coolant radiator.
24. Oil radiator.
25. Starboard coolant thermostat.
26. Avimo coupling, electrically bonded.
27. Oil pipe to airscrew hub.

EXHAUST SYSTEM. The material normally employed in the manufacture of manifolds must withstand heat and also be suitable for deep pressing. Mild steel has been used with some success, but the former requirement is not satisfactory. Several alternative materials have been tried, and although more expensive, they make up for this by the longer anticipated life. Inconel is one of these, and it can be welded satisfactorily by an approved welder.

The modern manifold or exhaust ring is made up of a number of sheet metal pressings which are welded together in the former case, and welded and riveted together in the case of exhaust rings for the radial type engines.

With inline engines the manifolds may be in one piece for each bank of cylinders, or they may be made up of several components telescoping into each other. In either case interchangeability in part and as a whole must be ensured. With suitable dies the pressings are very uniform, but careful inspection is required to make sure that dragging on the die has not started a small crack. The welding on of the flanges securing the manifold to the cylinders must be done whilst the job is mounted on a rigid and accurate jig. The finished job must be offered up to a dummy power unit to ensure adequate clearances at all points, particularly the cowling panels.

When finally fitting the manifolds to an engine, it is important that there shall be no leakage at telescopic joints or exhaust ports as otherwise serious damage might occur to structural members as well as the more inflammable parts such as high tension leads, etc. The exhaust flange nuts are usually made of brass and are smeared with graphite paste before fitting. This will facilitate subsequent removal with a less tendency to undo the stud in the aluminium block and obviate the more difficult job of effecting a satisfactory replacement.

Tail pipes are fitted on some aircraft, and it is important to provide telescopic expansion joints if called for on the drawings.

In dealing with the repair of these parts, it is logical that burning is most likely to be apparent where the heat is greatest, that is to say where the hot gases impinge as they leave the exhaust ports. A good design may not suffer in these respects, but the trouble will be met and cracking in other places will also occur. Welding often makes a good repair and prolongs the life of the part very considerably.

Some radial engines, such as the Lynx or Cheetah, have cylinders which screw into the crankcases. Care must be exercised to see that the faces of all the exhaust ports are in one plane before finally fitting the manifolds. This is normally checked with a straight edge.

Exhaust rings for other radial engines are more elaborate and may incorporate manually operated trailing edge flaps for controlling the cooling air passing over the cylinders. It is thought that repairs to such a component would have to be done by the makers, but the inspector has much to do to see that the ring is properly fitted and adequately locked at every point. The operation of the trailing edge flaps and locking of all pins associated with them are equally important.

Cooling System. With radial engines the exhaust system often forms part of the cowling ring through which the air enters. The air flow at the entrance to the cowling is radial in direction and the amount which enters is small and the velocity low. The entrance to the cowl is designed to redirect the air flow to the cylinder heads and buried sparking plugs, and this is accomplished by the assistance of numerous inter-cooler baffles. Further control is provided by means of adjustable trailing edge flaps fitted all round the rear edge of the cowling. Careful check is required to see that all baffles are fitted correctly, tightly, and properly locked.

With liquid-cooled engines there are additional components such as radiators, header tank, pumps, numerous pipes, and in some installations thermostats. Where the system is working under pressure, it

may be as high as 25 lb. per sq. in. under the worst conditions, consequently all parts of that system would have to pass pressure tests at double that pressure, and release notes should be checked to see that this has been done by the sub-contractor.

Heat always flows from one body to another which is cooler and passes from the coolant to the cylinder jacket far more readily than from the jacket to the surrounding air, owing to the latter being a poor conductor. Therefore to get the best cooling effect it is important to keep the radiator free of sand and dirt which, apart from causing back pressure in the system, reduces the transfer of heat to the air and the temperature drop across the radiator is reduced also. The straps supporting the circular radiators are packed with felt to effect additional air sealing between the radiator and the air scoop. An air vent cock is usually fitted to the outlet pipe on the radiator.

Pipes must be of the correct bore, gauge, and material. The connections attached to the ends must be of approved pattern. Straight runs of piping are desirable to eliminate air locks and sheet metal contour gauges are required for inspection purposes, so that length, squareness of ends, etc., can also be checked. Copper, tungum, etc., are used for tubes and unions are brazed to the pipes. Soft soldering is not permitted. A drain plug is provided at the lowest part of the system when the aircraft is on the ground, and any other place where coolant would not otherwise drain away. This precaution is necessary to safeguard the system against frosty conditions.

All connections must be checked for tightness and to see that they are adequately locked, as apart from the loss of coolant there is always the risk of air being admitted. The complete system must also have a static flow test with hot coolant before and after engine running. Topping up with coolant may be necessary after air has been expelled. All leaky joints must be carefully rectified before completing the bonding.

Thermostats are helpful in reducing cylinder wear due to the shorter period in warming up the engine when cold. They must be adjusted to maintain temperature control within the range specified for the particular installation and a freezing mixture must always be used. If it is a water system, the addition of 30 per cent ethylene glycol will probably be sufficient. The mixture commences to freeze at $-15°$ C., a condition approximately equivalent to 20,000 ft. altitude. If ethylene glycol is the coolant, it is usual to use the treated product, which it is claimed obviates corrosion of certain non-ferrous parts of the radiator.

Horseshoe type header tanks, if pressure-tested as separate units, must be fitted with stretcher bars to prevent distortion.

With certain air-cooled inline engines, the air from the slipstream is conducted past the cylinder heads by means of ducts, baffles, and passages. These must conform to the drawings in every detail, as any omission or displacement might impair the cooling of a particular cylinder, and if the permissible operational temperature was exceeded the detonation characteristic of that cylinder might be altered.

COWLINGS. With radial engines, the exhaust ring almost invariably

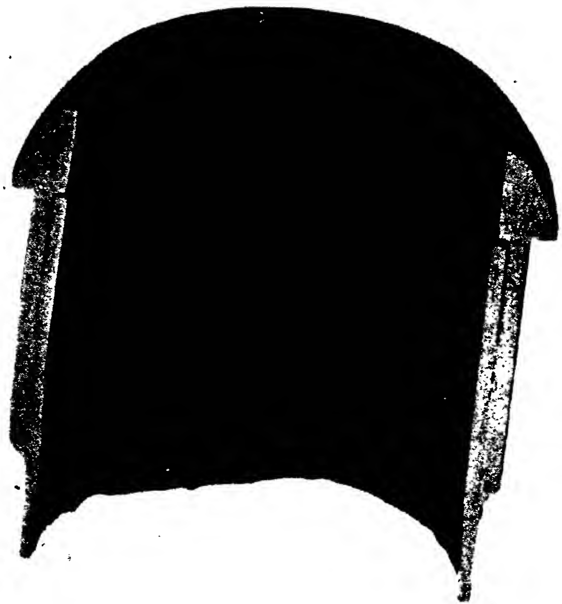


Plate XXIIa. Oil Pipe Nipple, Illustrating Defective Brazing

Plate XXIIb. A Silver Soldered Copper to Steel Pipe Joint

Sectioned through a ball of extruded solder which partially blocked the pipe

forms the front portion of the cowling, and is blended to conform to an annular ring surrounding the engine. This ring is mounted on the bulkhead which in all probability will form part of the power unit also. The mounting may be such that there is a space between the rear of the ring and the fuselage proper, which can be opened or closed by means of hinged flaps to provide a means of controlling the air required for cooling the engine.

With liquid-cooled engines the cowling is more elaborate and may include top and bottom panels attached in various ways to cowling rails and rings. The panels are made from mild steel or aluminium sheet, in the soft condition. The surface of the sheet must be free of blemishes or wrinkling before processing commences. For large quantity production an elaborate metal die is produced which ensures that all panels are alike, but this is expensive, and it may be that for a limited number the panels are hand-made, in which case a wooden former is used. Special attention must be paid to surface finish and freedom from cracks, pitting or scale. A scriber line can be the start of a fatigue crack, accelerated by vibration and panting of the panel. The riveting of reinforcing strips requires care, and uniformity of rivet spacing is just as important as a well-snapped rivet in a good fitting hole. The fasteners provided for securing the panels to the strips on the mounting must all be jig positioned, and when the panel is fitted all fasteners must be tight and free from chatter.

Panel openings may be required for adjustment of certain accessories, cleaning the oil filter, tubes for conveying cool air to the generator, and sometimes the high-pressure compressor, starting handle, etc. The air intake may be incorporated in one of the panels or the pipes may come through them. In the first case a hot and cold air intake flap may be embodied, whilst in the latter it is not unusual to fit an air cleaner, particularly when sandy aerodromes are used.

Panels must be clear of all pipes as otherwise chafing when the engine mounting distorts might do some serious damage. A certain amount of patching would be permitted on panels when overhauling a power unit, but this would normally be covered by a repair scheme in agreement with the designers.

Good ventilation inside the cowling of liquid-cooled engines should be provided as distributors, and similar moulded parts are liable to distort if the temperature is excessive. Similarly the crankcase should be kept as cool as possible, and well-ventilated, so that big-end temperatures are reduced and the life of the lubricating oil increased.

Pipe Lines. Swaging of certain materials, particularly in the thinner gauges, is not practical owing to the risk of cracking, and where olive joints are still used care is required in bell mouthing the ends of the tube to avoid burrs and scratches. The use of coarse emery is sufficient to start a crack, and dents in pipes are likely to impair the flow of the liquid concerned.

The run of the pipe lines should be as direct as possible, but clear of other pipes and cowling panels. They should be adequately supported by brackets or clips, using packing material at each support. If the pipes pass through the bulkhead, packing is even more important.

Rubber hose type connections should be fire-proofed with a metal gauze covering, and in repair work such couplings are normally suspect and consequently must be rejected.

Cocks should not be fitted in positions where undue strain is imposed on the piping when operating them, as failure might be accelerated by vibration, which hardens copper, making it brittle.

Joints incorporating rubber, and others not providing a positive electrical passage, must have bonding wires fitted across them in an approved manner. The clips must grip the tubes tightly after removing enamel or other protective coating which is not a good electrical conductor. This bonding is to eliminate the danger of sparks between two members, due to static charges which may be of different potential.

ACCESSORY GEARBOXES. These are as yet only fitted on the larger aircraft, and are designed so that those accessories which are not essential to the functioning of the engine may be accommodated elsewhere than on the engine. This considerably facilitates installation, and reduces the lengths of pipes to these services. The gear box can be driven by a carden shaft, through a right-angle drive, or from an extension shaft from the engine, but still forming part of the engine. The position of the box can be decided to suit the space available by selecting the type of drive.

The gear box is self-contained as regards lubrication of the drives, and can accommodate all the auxiliaries normally required. These might include the following—

Generator for charging an accumulator to use in conjunction with electric starting of the engine, and aircraft lighting. Hydraulic pump for retractable undercarriage and flaps. High-pressure air compressor to maintain an air bottle for operating wheel brakes and sometimes engine starting. Low-pressure air compressor for use with the automatic pilot when fitted.

Vacuum pump for certain aircraft instruments.

Gear boxes would normally be tested on an engine during acceptance tests or on a rig under similar conditions. Slave accessories would be fitted to provide the necessary loads on the drives. The total power required to drive six auxiliaries might be as much as 30 h.p.

Damaged gear boxes and those requiring normal overhaul would be repaired by the makers of the engine, and the various accessories would be overhauled as necessary by the appropriate approved manufacturer.

All the precautions detailed for the engine, apply equally to the gear box, special attention being required on assembly to secure the correct gear tooth clearances, particularly when shimming is not provided.

GENERAL. Experience shows that studs for securing manifolds, accessories, brackets, etc., are liable to become damaged, and in some cases the stud is broken or twisted off, rendering the remaining piece difficult to extract. Any of the following methods should enable rectification to be effected without scrapping a part or removing the engine from the aircraft.

(a) Drill a hole in the centre of the stud stump and drive a

hardened square drift into it. This should provide enough grip to permit unscrewing the piece. If this fails, adopt method (*b*).

(*b*) Open out the hole in the stump just slightly smaller than the root diameter of the stud. A carefully applied standard tap will then remove the remaining metal threads.

(*c*) If the equipment is available, drill a hole and tap a reverse thread in it. With a suitable spindle the stump should easily come out.

If a stud is removed from an Al part it is almost certain that the new stud will have to be oversize; alternately the hole can be rendered standard by fitting a dural or stainless steel bush, if there is sufficient metal around the hole to permit this. The job requires every care and the bush, when tightly in position, requires pinning or locking in an approved manner. Stud holes are normally provided with air vents at the bottom to prevent the casting bursting when studding the part. The stud does not of necessity have to bed on the bottom of the hole, but swarf left inside might fill up the space and cause the casing to split.

Storage of Raw Material and Finished Parts

The stores must be dry, warm, and well ventilated. It should be as far as possible from shops containing pickling or plating baths, and a marine atmosphere is to be avoided.

Raw material should be readily identifiable with its release note, and markings should be transferred to pieces remaining if the part with the original marking has been consumed.

Sheet should be stored horizontally on wooden shelves, whilst tube and bars should be accommodated on racks, if adequately supported.

All steel parts should be greased, particularly bright drawn bar, as this is often supplied within ·002 in. of the finished dimension of the part and surface pitting might render the bar unserviceable.

Finished machined parts should be thoroughly greased and stored in unpainted wooden bins and racks or stands should be provided for crankshafts, airscrew shafts, and complete sub-assemblies. The thread on the end of the airscrew shafts requires a metal cap to protect same against damage.

Cylinder block assemblies should always travel on rigid cradles to prevent bowing. If, however, bowing is suspected, this can be checked with a straight edge placed along the camshaft bearings.

Pistons should never be stored on their sides or on top of each other. Pitting of aluminium pistons may occur in store if they have been used with leaded fuel, as the lead bromide absorbs moisture and causes chemical corrosion, producing a brown stain. Rust preventative E.G. 174 is, however, an antidote.

Ground Engineers' "C" Licence

General. A person holding a "C" licence is not permitted to manufacture any parts, but may carry out minor repairs or rectifications on parts comprising the power unit, with certain exceptions, such as accessories manufactured by firms other than the engine makers.

He is expected to be able to top overhaul an engine, fit new replacements that may be necessary, supervise the testing and tuning of the rectified engine either on a dynamometer or with a calibrated airscrew, and finally instal it into the aircraft. The whole of the above operations will be covered by his certificate in the engine log book. He must also be able to maintain the power unit in good order by daily inspections and adjustments that may be required from time to time, and issue a daily certificate for flight only when he is satisfied that the engine is fit to go into the air.

Most of the knowledge required for a "C" licence has already been included in the notes covering the "D" licence, so in order to avoid unnecessary repetition reference will be made as necessary to the parts of those sections which cover the two categories. In these notes it is assumed that the applicant for a licence has had an apprenticeship and has a knowledge of internal combustion engines.

Dealing with the A.N.D. regulations and orders, a knowledge of which forms part of the oral examination syllabus, the following sections should be studied in addition to those mentioned on the first page of this book.

Section IV. This contains instructions for the issue and preparation of daily certificates of safety for flight.

Section VIII. This details the instruments, associated with the power unit, that must be carried in the aircraft.

Section X. This calls for the maintenance of a log book for each engine if the aircraft is used for hire and reward flying. Entries will include all running repairs, adjustments, replacements, and modifications incorporated, followed by a certificate by the responsible "C" licensed ground engineer.

A person applying for a "C" licence must of necessity have obtained practical experience of aero-engine maintenance and top overhauls. The section headed "Experience" details that which is required to satisfy the examiner. Complete overhaul experience is, however, unnecessary.

Top Overhaul. The engine running time before a top overhaul is due is normally specified by the manufacturer of that particular type of engine, and would be based on accumulated experience of that type. The ground engineer would be wrong in exercising discretion in extending this time, unless there were some unusual circumstances. The fact that the engine appeared in every way to be normal should not be allowed to influence his ruling to proceed with the overhaul. It may happen that a top overhaul will have to be contemplated before the maker's time is approached.

Air lines soon accumulate experience of a particular type of engine, and consequently are in a very good position to set their own standard both for operating conditions and period of running before overhaul. With some types of engine, the top overhaul is dispensed with altogether, but partial overhauls are made at intervals until a complete overhaul becomes due. These partial overhauls may include the changing of a component which has been given a limited life because of age or design, the introduction of an essential modification, normal

maintenance due to the development of a fault, excessive oil consumption, etc.; top overhauls can sometimes be carried out without removing the engine from the airframe, and it must be clearly understood that dismantling can proceed only as far as the removal of cylinders and pistons, carburettors, magnetos, starters, airscrews, reduction gear, accessory gear boxes if fitted, external pipe work, filters, thermostats, manifolds, priming system, etc. The extent of stripping will be sufficient to enable a check to be made on the fit of the connecting rods on their pins. With reference to the inspection after stripping, test, and rectification of parts removed from the engine, sections headed "Inspection prior to Overhaul" and "Inspection during Overhaul" give full details of the work involved. The engine maker usually provides a list of permissible limits for worn parts. A working knowledge of micrometers, verniers, etc., is essential, and you are referred to *Engineering Inspection*, published by Sir Isaac Pitman & Sons, Ltd., for such information. It should be quite clear that only minor rectifications are allowed, and work involving machining, welding, etc., must be covered by a "D" man's certificate. New parts, properly released, can be fitted. The overhaul of magnetos, V.P. airscrews, instruments, etc., are certified by a person holding an "X" licence, although the normal external maintenance adjustments may be permitted. Detail is provided on these points in sections headed "Accessories," "Starters," and "Testing with Airscrews."

The reassembly of the engine proceeds in the reverse order, and the main points in connection therewith are dealt with in the section headed "Engine Build."

ENGINE TESTING. If the firm's equipment does not include a dynamometer or the engine is overhauled in position in the airframe, it will have to be tested by calibrated airscrew or under certain circumstances by the actual flight airscrew, in order to prove correct assembly and functioning. In either case full details are given in the section headed "Testing with Airscrews." If a dynamometer is available, reference should be made to the various sections devoted to its operation. Particular attention will have to be paid to the tuning of the engine before any prolonged test is contemplated. Some engines may require careful running in, and the maker's instructions regarding incremental running or other precautions must be followed. The duration of the test will largely depend on the number and importance of any new components fitted, and to some extent the classification of the aircraft for which the engine is intended. For further particulars, see Design Leaflet C3 (A.P. 1208).

The extent of dismantling after test rests largely with the ground engineer, and if a straight overhaul has taken place without major replacements no strip would normally be necessary, providing the functioning was in every way satisfactory. If, for example, one or more pistons had been changed and new ones were fitted, it would be correct to examine them again to make certain that their condition after test was satisfactory.

The test would include a check of slow running, drop in r.p.m. on single ignition, specific fuel consumption, power, acceleration, oil

pressure, etc. Attention should also be paid to vibration and the presence of oil leaks.

Engine Installation. The ground engineer in the "C" category is expected to be able to change an engine and fit another one that has been overhauled, together with all the services associated with the power unit. The work involved is covered in the section headed "Power Units," but a few of the sub-sections are only relevant to the "D" man's duties because he only is permitted to certify any actual manufacture of parts, whilst the "C" man is only permitted to incorporate new parts if properly released. He would be allowed to anneal and set small copper pipes and attach unions if full information was available. He could change loose studs, adjust the starter clutch setting, or the thermostats, and similar routine items.

The accuracy of the engine mountings is normally the responsibility of the "A" licensed man, as also are the radiators, tanks, and cowlings, but the "C" man also must be satisfied that these items are satisfactory for his engine.

The magneto earthing system, including the switches, must have an electrical test for continuity, and a Megga test for insulation in accordance with Leaflet D1 of A.P. 1208.

Controls must be synchronized if more than one engine is fitted in the aircraft. All accessories and fittings must be verified to ensure that they are of approved types.

Maintenance. A daily inspection of the power plant must be made (in accordance with A.P. 1208) if the aircraft is in regular use. This would include such things as the following—

Correction of any faults reported on the previous flight, and note of any items which may be deferred if for any reason they cannot be rectified at once.

Check the quantities of fuel and oil in the tanks, and ensure that they are approved brands.

Examination of high tension leads and their attachment to the plugs.

Locking of all pipe line unions and tightness of supports and clips.

Clearances of push rods, valve rockers, etc. They may have to be done when the engine is hot.

Check of compressions in each cylinder.

Ensure that all controls have a full range, freedom of operation, and all pins are tight and locked.

Examine the induction system for leaks.

Lubricate any external moving parts as indicated by the makers.

Check the tightness of manifolds and cowlings.

Examine all pipes and connections for leaks.

Ensure that the airscrew is securely fixed and the spinner properly fitted and locked.

If the engine is liquid-cooled see that the correct coolant is used and that the header tank is full.

Run up the engine and verify that all services are functioning and instruments are recording properly, including the earthing switches. With air-cooled engines the flaps must be open. The faults and their

remedies in connection with engine running are dealt with very thoroughly in the section on "Location of Faults."

In addition to the daily inspection, periodic inspections should also be made at intervals of, say, 5, 10, and 25 hours' flying, or at intervals usually specified in the makers' handbooks. The following items would be amongst those which should receive attention—

Examination of oil filters for foreign matter. See page 51.

Cleaning and reconditioning of sparking plugs, connectors, elbows, etc.

Check for deterioration of high tension leads and ignition harness.

Examination for cracks around manifolds and cowlings.

Check the tightness of engine-mounting bolts.

Magneto and distributor maintenance to be carried out.

Check the track of the airscrew blades, if of wood.

If rubber connections show indications of flaking, particularly on the insides, they must be replaced.

Flow through coolant system should be verified.

Examine valve springs for breakages.

SUPERCHARGED ENGINES. Supercharged types of engine are not normally found amongst the civil types of aircraft, except on the air lines. However, sufficient has been said in another part of this book to give a very good insight into the subject, including of course boost controls, boost gauges, and setting the throttle gate position.

INSTRUMENTS. The checking of pressure gauges and thermometers is mentioned on page 92, but it is also necessary to have a general idea of the construction and functioning of these instruments. It is suggested that opportunity should be taken to examine one of each type when occasion arises. It will be found that with both these instruments the pressure created inside the tubes leading to the gauges operates mechanism on the Bourdon tube principle.

Revolution indicators are usually run at one-quarter engine speed by interposing a 4 : 1 gear box. The flexible cable to the indicator must not be fitted with a bend in excess of a 9-in. radius.

Accuracy should be within 2 per cent. This can be checked by means of an Ashdown Rotoscope, or by comparison with another instrument known to be accurate.

Oil and fuel tank gauges must be checked periodically for accuracy. This can be done by running off a quantity of the liquid and adding a similar amount to the tank, noting the gauge reading at every stage.

APPENDIX I*

XX. BRINELL HARDNESS NUMBERS AND APPROXIMATE TENSILE STRENGTH OF STEEL

Diameter of Impression in mms.	Brinell Hardness No. 3000 kg. load	Approx. tensile strength tons/sq. in.	Diameter of Impression in mms.	Brinell Hardness No. 3000 kg. load	Approx. tensile strength tons/sq. in.
2·00	946	206·0	4·50	178	40·2
2·05	899	196·0	4·55	174	39·2
2·10	857	187·0	4·60	170	38·3
2·15	816	178·0	4·65	166	37·4
2·20	779	171·0	4·70	163	36·6
2·25	745	162·0	4·75	159	35·8
2·30	712	155·0	4·80	156	35·1
2·35	681	149·0	4·85	152	34·2
2·40	654	142·0	4·90	149	33·8
2·45	626	136·0	4·95	146	33·3
2·50	601	131·0	5·00	142	32·7
2·55	577	126·0	5·05	139	32·0
2·60	555	121·0	5·10	136	31·3
2·65	534	116·1	5·15	134	30·9
2·70	514	112·0	5·20	131	30·2
2·75	495	107·9	5·25	128	29·5
2·80	477	104·8	5·30	126	29·0
2·85	460	100·2	5·35	123	28·4
2·90	444	96·8	5·40	121	27·9
2·95	429	94·0	5·45	118	27·5
3·00	415	91·0	5·50	116	26·5
3·05	401	88·0	5·55	113	26·0
3·10	388	85·2	5·60	111	25·5
3·15	375	82·3	5·65	109	25·0
3·20	363	79·1	5·70	107	24·5
3·25	352	76·8	5·75	105	24·0
3·30	341	74·4	5·80	103	23·5
3·35	331	72·2	5·85	101	23·0
3·40	321	70·0	5·90	99·2	22·75
3·45	311	67·8	5·95	97·3	22·5
3·50	302	65·8	6·00	95·5	22·0
3·55	293	63·0	6·05	93·7	21·5
3·60	285	61·3	6·10	92·0	21·0
3·65	277	59·6	6·15	90·3	20·75
3·70	269	57·8	6·20	88·7	20·5
3·75	262	56·4	6·25	87·1	20·0
3·80	255	54·8	6·30	85·5	19·75
3·85	248	53·4	6·35	84·0	19·25
3·90	241	51·8	6·40	82·4	19·0
3·95	235	51·0	6·45	81·0	18·75
4·00	229	50·8	6·50	79·6	18·25
4·05	223	50·2	6·55	78·2	17·75
4·10	217	48·8	6·60	76·8	17·5
4·15	212	47·7	6·65	75·4	17·5
4·20	206	46·4	6·70	74·1	17·0
4·25	201	45·3	6·75	72·8	16·75
4·30	197	44·2	6·80	71·6	16·5
4·35	192	43·2	6·85	70·4	16·25
4·40	187	42·2	6·90	69·0	16·0
4·45	183	41·2	6·95	68·0	15·75

For 220 and upwards, add 5 to 7·5 per cent for tensile strength if dealing with normalized Carbon steels.

By courtesy of John Brown & Co., Ltd.

* From the *Handbook of Aeronautics*, Vol. I. (Pitman, 25s.)

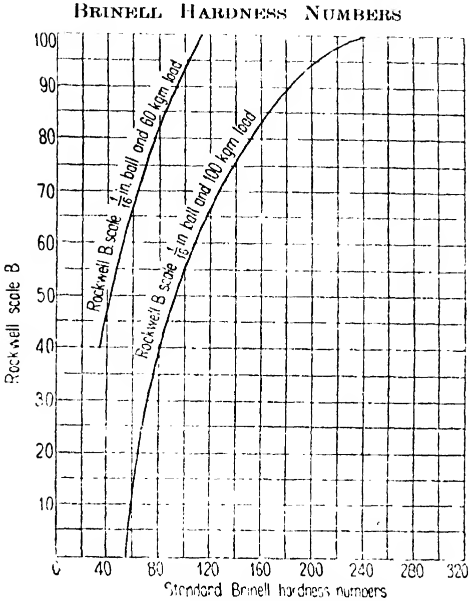


FIG. 1 CONVERSION TO STANDARD BRINELL HARDNESS NUMBERS OF ROCKWELL B SCALES

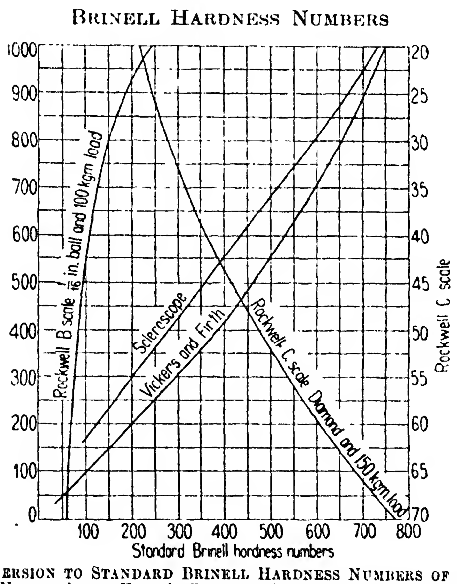


FIG. 2. CONVERSION TO STANDARD BRINELL HARDNESS NUMBERS OF ROCKWELL (C AND B SCALE), VICKERS' AND FIRTH'S DIAMOND HARDNESS NUMBERS AND SCLEROSCOPE

Figs. 1 and 2 from "The Inspection of Metals and their Alloys," by L. W. Johnson, M.C., Met. *The Journal of the Royal Aeronautical Society*, June, 1930.

APPENDIX II

BRIEF DEFINITIONS OF TERMS AND NAMES WITH WHICH A GROUND ENGINEER, HOLDING A "D" LICENCE, SHOULD BE FAMILIAR

CLASSIFICATION HEADINGS

1. Air Navigation Directions
2. Materials
   (*a*) Classification of Steels
   (*b*) Ferrous Material
   (*c*) Non-ferrous Material
3. Material Testing
4. Material Defects
5. Approved Protective Processes
6. Manufacturing Processes
7. Heat-treatment
8. Accessories
9. Engine Testing
10. Fuels
11. Engine Data

1. AIR NAVIGATION DIRECTIONS

Approved Firm. This is any firm approved by the appointed inspecting authority for the manufacture, inspection, and release of aircraft parts. (See page 3.)

Approved Release Note. A document covering the inspection and release of aircraft parts manufactured by an approved firm. The release note will include a certificate embodying the Air Ministry reference under which approval of the firm was granted.

Certificate of Airworthiness. This is a certificate given when a machine and its power plant comply with the prescribed regulations.

Ground Engineer. A person authorized to certify the safety for flight of an aircraft, or parts thereof, in accordance with the regulations in force.

" Type " Engine. An engine which has satisfactorily completed a Civil Type Test, and for which a technical certificate has been issued. "Subsequent" engines must be identical to the "Type" engine, except where approved modifications have been added.

2. MATERIALS

(a) Classification of Steels

Air-hardening Steels. These steels contain elements such as Ni and Cr, which have the effects of slowing down the transformation of the steels, when cooling through their critical points, to such an extent that rapid cooling becomes unnecessary.

Alloy Steel. An alloy steel consists of one or more elements other than carbon, added specifically to improve one or more of its useful properties. The elements V, Cr, Mn, Co, Ni, Mo, and W, all of which have high melting points, are those usually employed. For aircraft steels the common alloys are Ni from 3 per cent to 4·5 per cent; Cr from ·5 per cent to 1·5 per cent. The quantities and subsequent heat-treatments determine the ultimate strengths.

Austenitic Steel. This steel is usually high in Ni, Cr, or Mn. The physical properties cannot be varied to any great extent by the usual method of heat-treatment. It does not harden by a quenching treatment from high temperatures, and remains non-magnetic at ordinary temperatures. It is very resistant to corrosion and erosion by hot gases, and retains its strength well at high temperatures.

Carbon Steel. This embraces—

(i) Mild steel containing up to ·25 per cent C.
(ii) Medium steel containing from ·25 per cent to ·70 per cent C.
(iii) High carbon steel containing from ·70 per cent to 1·8 per cent C.

In all cases the C is combined as a carbide; in addition, Mn and Si may be present within prescribed limits.

Ternary Steel. This steel contains iron, carbon, and one alloying element only.

Quaternary Steel. This steel contains iron, carbon, and two alloying elements.

Complex Steel. This steel contains iron, carbon, and three or more alloying elements.

Stainless Steel. This is a steel with high Cr content. It is non-corrosive after heat-treatment has eliminated the free carbides. Stainless Cr-Ni steels are manufactured under the names of "Staybright." "Anka," etc. Steel to B.S. Specification S.62 is often used for inlet valves.

Straight Steel. This is a carbon steel which does not include any toughening elements such as Ni, Cr, etc.

(*b*) Ferrous Material

Case-hardening Steel. One containing not more than ·2 per cent of carbon. The following steels with proprietary names fall in this class—

"Ubas." This is manufactured by Messrs. Flathers, and the composition comes within B.S. Specification 2.S.14.

"Hicore." This is a nickel chrome molybdenum steel which conforms to B.S. Specification S.82.

Era H.R.1. This is a high nickel high chromium austenitic steel made by Messrs. Hadfields. The appropriate specification is D.T.D.49B. This material is used mainly for inlet and exhaust valves.

Hykro. This is a steel with high Cr content and is suitable for nitrogen hardening. Steel to B.S. Specification No. 306 is suitable for all engine parts. Steel to B.S. Specification No. 317 is used primarily for cylinders. The Brinell hardness in both cases is about 850 after nitriding. See all "Nitralloy."

Invar. This is a nickel iron containing 36 per cent of nickel. It has an exceedingly low rate of expansion, and is very resistant to water corrosion.

K.E. 965. This is a high nickel high chromium austenitic steel made by Messrs. Kayser Ellison. The appropriate specification is D.T.D.49B. The steel is used principally for inlet and exhaust valves.

Nitralloy. A steel to specification D.T.D.87 that can be surface hardened by the Nitriding process. Specification D.T.D.228 is also suitable, but owing to the absence of Al the process takes longer. Steel to B.S. Specification No. 228 is more ductile than other nitriding steels and is less suitable for nitrogen hardening, the Brinell hardness being about 650. Steel to B.S. Specification No. 87 has a Brinell hardness of about 1050 after nitriding. See also "Hykro."

N.M.C. This is a 12 per cent nickel manganese chrome steel made by Messrs. Firth Derihon, which conforms to Specification D.T.D.247. It is used extensively for valve seatings, because of its resistance to shock loadings at high temperatures.

Pitho. This is a high carbon steel used for valve ends and similar parts.

Sandvik. This is a nickel chrome air-hardening steel.

Thermocrome. This steel conforms to D.T.D. Specification No. 233 and is used by Messrs. Wellworthy Ltd., for piston rings.

(*c*) Non-Ferrous Material

Alpax. This is an aluminium alloy suitable for intricate castings. It contains about 13 per cent silicon, which facilitates the flow of metal. It conforms to B.S. Specification L.33. In the fully modified condition, the ductility and physical properties of the material are improved. "Wilmil" is the name of a similar class of material.

Silumin is a high Si-Al alloy and, like Alpax, there are Beta and Gamma variations according to the heat-treatment, which is made possible by the addition of Mg.

Bearing Metal. The following are the most usual crankpin bearing metals—

> HOYT 11, which conforms to B.S. Specification 2.B.22.
> HOYT 11.D., which conforms to Specification D.T.D.214.
> HOYT 11.D. (modified). Specification D.T.D. 244.
>
> The latter two materials are used to some extent on Bristol and Armstrong-Siddeley engines.
>
> CADMIUM, which conforms to Specification D.T.D.217.
> LEAD BRONZE, which conforms to Specifications D.T.D.229 and 274.
> GLACIER, which conforms to B.S. Specification 2.B.21.

Birmabright. This conforms to D.T.D. Specification No. 165 and contains ·5 per cent Mn, 3·5 per cent Mg, the remainder being Al.

Brightray. This consists of 80 per cent Ni and 20 per cent Cr. It is used primarily for coating the head and seat of inlet and exhaust valves and provides a protection against corrosion at high temperatures and lead attack.

Brightray work hardens. It is softer than Stellite and there is a less tendency to cracking. Coatings are difficult to apply, but porous or patchy places may be removed and re-coated.

Carobronze. This is an extruded material containing 92 per cent pure electrolitic copper and 8 per cent tin; ·25 per cent of phosphorus is present, but this is controlled. The appropriate specification is T.52. The material is normally used for bushes, and is supplied in tubular form, either heat-treated, hard, or annealed.

Constantin. This consists of 45 per cent Ni and 55 per cent Cu. It is used primarily for thermo couples.

Cupro Nickel. This consists of 79·6 per cent Cu, 20 per cent Ni, 0·4 per cent Mn.

Duralumin. This is an aluminium alloy conforming to Specification 4.L.1. It can be obtained in all the usual forms, including extruded and forged material. It requires heat-treatment followed by a natural age-hardening.

Elektron. This is a name covering a range of magnesium aluminium alloys. It is available as castings, bars, tubes, forgings, and can also be extruded. Specification D.T.D.88B covers the requirements of forgings, and Specification D.T.D. 59A covers those for castings. Its specific gravity is 1·82.

Gallimore Metal. This consists of 90 per cent Cu and 10 per cent Sn and is used largely in radiator construction.

Hiduminium. This covers a range of Messrs. High Duty Alloys, aluminium alloys evolved by Messrs. Rolls-Royce. The analysis includes Cu, Ni, Mg, Fe, Si, and Ti. The latter is understood to act as a refining agent. The following specifications relate to this class of material—

> L.40, R.R. Specification 56, for forged work.
> D.T.D.131A, R.R. Specification 53, for die-cast pistons.
> L.42, R.R. Specification 59, for forged pistons.
> D.T.D.133B, R.R. Specification 50, for sand and die castings.

Inconel. This consists of 75–80 per cent Ni, 11–13 per cent Cr, 6–8 per cent Fe, and impurities up to 2 per cent. Its ultimate stress fully annealed is 35 tons per sq. in., but as hard-drawn wire it is as high as 85 tons per sq. in. It has a high resistance to corrosion at high temperatures

and is used for exhaust manifolds. It can be brazed, silver and soft soldered, and welded. It is not subject to weld decay, but a protective flux is applied as a paste. The welding wire should be bright annealed and soft, either cut in strips from the sheet or in the form of wire.

Monel Metal. This material contains from 64 per cent to 70 per cent Ni, 2·5 per cent (max.) Fe, 2 per cent (max.) Mn, and the remainder copper. D.T.D. Specification 10B covers sheet, and D.T.D. Specifications 192, 196, and 200 cover bars, etc. This material is resistant to all forms of corrosion, and has been used extensively for valve seatings.

Nickel Silver. This is a Cu-Zn alloy with from 10 to 14 per cent Ni.

Stellite. This comprises 4 to 16 per cent W, 30 per cent Cr, and 66 to 54 per cent Co. The higher the tungsten, the more brittle the material becomes. It is highly resistant to hot and cold corrosion attack of leaded fuel, and has been used as a facing for valve seats and seatings. It is also applied to the tips of valve stems on account of its resistance to abrasion. The coefficient of expansion differs from that of the austenitic steels normally used for valves, and cracks on the facings may be detected.

Stabalite. This is a material used for mouldings in ignition coils and similar electrical fittings.

Textolite. This is made up of layers of canvas impregnated with synthetic resin, which are compressed together in a hot press. It is used for gear wheels of magnetos.

"Y" Alloy. This is an aluminium alloy which is largely used for pistons. The material is resistant to atmospheric and marine corrosion. It has good physical properties at high temperatures. Specification L.43 covers forgings and stampings, and B.S. Specifications 2.L.24 and L.35 cover castings, etc.

3. MATERIAL TESTING

Brinell Number. (See page 13 for full particulars.) In addition, tables are included in Appendix I.

Brittleness. This is the opposite property to "toughness" and is the lack of resistance to fracture when subjected to shock or other loads.

Creep Stress. The permanence of dimensions on test bars under continuous stress at room and/or elevated temperatures. It is a fatigue stress set up by a dead load, when stretching may occur considerably below the normal yield point, particularly at elevated temperatures. The load, period of application, and temperature range are important factors.

Ductility. The property of being permanently extended by a tensile stress.

Elasticity. The capacity of a material to return to its original dimensions on releasing the load causing the change in dimensions.

Elongation. (See page 7 for full particulars.)

Etching. The application of an acid solution to finished steel parts, after immersion in petrol and caustic soda to remove grease, etc., in order to show up any cracks or surface defects. The deposit so formed is removed with acetone and the part is then dried, after which acid would ooze from any cracks that may be present.

Hardness. The degree of resistance to penetration or wear by abrasion.

Impact Value. (See page 12 for full particulars.)

Limit of Proportionality. This in effect is the elastic limit of a steel and is the point of a stress-strain curve where it ceases to be proportional.

Malleability. The property of being permanently extended either by forging, rolling, etc.

Modulus of Elasticity — When a tensile load is applied to a part, the modulus of elasticity (E) may be stated as the ratio of the load applied, to the extension produced, within the elastic limit, i.e. $E = \frac{\text{stress}}{\text{strain}}$. It is fairly constant for any given range of materials. For example—

For steels $E = 30{,}000{,}000$
For aluminium $E = 10{,}000{,}000$

Proof Stress. (See page 12 for full particulars.)

Reduction of Area. (See page 12 for full particulars.)

Stress. This is the resistance to change or deformation produced by an external load. It can be either tension, compression, or shear.

Strain. This is the deformation produced by a stress.

Sulphur Prints. If sulphur is well distributed in a steel it is not detrimental; but if sulphides are concentrated in large patches serious weakness in the metal may result. The following is a check for the presence of sulphur. The surface of the steel to be tested must be perfectly smooth, and all tool marks eliminated by progressive grades of emery cloth. A piece of bromide printing paper is soaked in a 5 per cent solution of H_2SO4 in water for a few minutes, and then placed on the prepared steel surface. Bubbles and excess liquid are squeegeed off, and after five minutes the paper is removed, washed in water, and fixed in hypo in the ordinary way. Sulphur, if present in excess, comes in contact with the acid and H_2S gas, which is liberated, blackens the printing paper. This procedure is indefinite for stainless steels.

Tenacity. The property of resisting fracture when under a tensile stress.

Toughness. The resistance to fracture when subjected to bending, torsion or shock loading.

Ultimate Stress. (See page 12 for full particulars.)

Yield Point. (See page 7 for full particulars.)

4. MATERIAL DEFECTS

(Ferrous)

Clink. Internal cracks in steel produced by tensile stresses set up in the ingot, probably as a result of too rapid heating.

Corrosion. This is the destruction of metal or alloy by chemical means.

Decarburization. This is the loss of C from the surface of steel. Iron reacts with O, forming "rust" at ordinary temperatures and adherent oxide scale on hot rolled or forged material. When reheated, the C in the adjacent steel begins to react with the iron oxide, which is reduced, the product of the reaction escaping as a gas. Migration of C is rapid and decarburization may take place to a depth of several thousandths of an inch.

In oxy-acetylene welding, the surface of the base metal and the welding rod may both become coated with iron oxide or scale while heating up to welding temperature and must be removed to secure a sound weld.

Erosion. This is loss of metal either rubbed or washed away.

Fins and Flashes. These are formed during the process of rolling the blooms into bars. They may become "laps" during subsequent passes through the rollers.

Flake or Snowflake. When an ingot is worked, pockets may occur in the steel where hard segregated layers of cementite have not properly

welded together owing to the evolution of dissolved hydrogen. The pocket, or cavity, has a bright silvery appearance, and is of circular form. The bright surface is due to the fact that no oxidization has occurred. The presence of an excess of Mo and the lack of control of the treatment of the ingot is thought to be associated with this defect; in addition, forging lessens the susceptibility to flake formation.

Hair-cracks. (See page 14 for full particulars.)

Laps. These are analagous to "roaks," except that they usually appear on the surface of the steel. Molten metal may splash on to the sides of the ingot mould when pouring, and then oxidize, being subsequently covered by rising fluid. They become much elongated by subsequent rolling. "Laps" and die-marks in bars, etc., may develop into cracks during subsequent heat-treatment.

Pipe. (See page 15 for full particulars.)

Roaks. These are cavities or blow-holes of carbon monoxide gas in the steel which become oxidized, and do not weld up again on subsequent working. When the steel is rolled into bars they appear as elongated cracks.

Seams. These are external flaws produced on the surface of tubes as a result of dirt on the die during the drawing operation.

Segregation. This refers to the segregation of C.S.P., etc., when cooling a mass of molten steel, and usually occurs near the top of the ingot, which is the last part to solidify. The carbon can, however, be partially redistributed by reheating.

Slag Inclusions. These often accumulate where "pipe" is found, and can be associated with insufficient skimming of the molten steel prior to pouring. They may also be present as oxides, sulphides and silicates, on the surface of the ingot, but would normally be removed when machining the outer skin prior to further working of the metal.

Weld Decay. This is a defect which may occur during the welding of stainless steel of the 8/18 Ni-Cr class, and is a carbide precipitation followed by inter-crystal corrosion resulting in the embrittlement of the material. Close control of the temperature is essential, and normalizing will not restore the structure. (See page 21.)

(NON FERROUS)

Blisters. These may appear on Al alloys during heat-treatment due to the release of free hydrogen which should have been removed by prior heating in a vacuum, a salt bath, or an electric oven, the latter being preferable. The presence of water vapour is undesirable.

Ribboning. The segregation of Pb in lead bronze bearings which after running have the appearance of irregular cracks, but which under a magnifying glass are found to be full of Pb.

5. APPROVED PROTECTIVE PROCESSES

(Only a brief description of each process is given)

Aluminizing. This consists of spraying the steel parts with molten Al, using a pistol for the purpose. It is then covered with bituminous paint prior to heating at 800° C. for about 20 minutes. When cold, the surface is smoothed with a scratch brush. The coating is ·007 in. minimum thickness and has a silvery appearance. Penetration is several thousandths of an inch deep. D.T.D. Specification No. 907 relates.

Calorizing. The steel part is packed in a drum containing granulated aluminium and heat applied externally. Alternatively, the part is immersed in a bath of molten aluminium. Steel so treated will withstand

high temperatures without undue oxidization or deterioration. The process lends itself, therefore, to the protection of exhaust manifolds, stub pipes, etc. This process does not give just a coating of aluminium, but actual impregnation of the base metal.

Cosletizing. This process provides a protective coating on iron and steel parts against rusting and corrosion. The process is somewhat similar to parkerizing, referred to later, except that the composition of the bath includes zinc phosphate, and phosphoric acid.

Fescolizing. This is the electrical deposition of metal, but differs from electroplating as regards the interlocking between the base and the applied metals which is obtained by the fescolizing process. The deposition is done in a cold bath, and perfect adhesion and cohesion are claimed. Nickel, chromium, and cadmium are usually employed.

Inhibitors. These are compounds which may be added to various supplies to prevent or restrain oxidization. The following are some of their applications—

(i) Addition to ethylene glycol tends to counteract radiator corrosion. Cupro nickel tubes, however, appear to be immune.

(ii) Tin compounds are used in lubricating oil with a view to retarding sludging.

(iii) During the pickling of wire, oxidized particles are rendered harmless by a suitable inhibitor.

(iv) Thin coatings are applied, by spraying, to bores of cylinders to protect them during storage.

Chromate Treatment. This is an external protection for magnesium alloy castings against corrosion. The part, after thorough cleaning, is immersed for several hours in a boiling solution containing potassium and ammonium di-chromate. When it is quite dry, it is usual to apply a coating of cellulose enamel, as the surface provided by the chromate treatment would not otherwise withstand the normal usage to which the part may be subjected.

Japanning. This is the application of enamel to a part in any manner, either for protective or decorative purposes.

Metallization. This is a protective process obtained by spraying molten metal on to the part to be protected. Aluminium and copper are usually employed for this purpose. In the case of exhaust manifolds and stub pipes, the process is completed by covering the coating with a bitumastic paint. and then subjecting the part to suitable heat-treatment in order to effectively bond the aluminium to the steel.

Parkerizing. This process provides a protective coating on iron and steel parts against rusting and corrosion. A preliminary cleaning of the surfaces should be carried out by sandblasting, after which the part is immersed for a period up to three hours in a boiling acid solution containing iron phosphate. The dimensions of the parts, as also in the case of cosletizing, are not materially altered.

Platinizing. This provides a protective coating of zinc to the external surface of air-cooled cylinders and other steel parts. The surfaces that are not required to be coated are suitably protected. The article is packed in a metal container with zinc dust, and subjected to a prolonged heating at a suitable temperature.

Sheradizing. This is a process for protecting the surfaces of easily corrodible steel parts with a coating of less corrodible metal, viz. zinc. The articles are heated at a relatively low temperature in contact with zinc dust; considerable alloying takes place although a thickness of only

about ·0005 in. remains on the surface. The articles are often "Rumbled" in a barrel, to ensure uniform contact with the metallic powder.

D.T.D. Specification No. 908 relates.

6. MANUFACTURING PROCESSES

Brazing. (See page 20 for particulars.)

Case-hardening. (See page 34 for full particulars.)

Cyanide Hardening. This consists of the absorption of C into the surface of steel parts whilst immersed in a liquid salt bath composed of sodium cyanide and sodium carbonate. The temperature of the bath may be between 800° C. and 950° C. and if the parts are left in for a long period, refining of the core may be required, followed by a normal quench in water. The following points should be noted—

(i) Parts should be dry and free of grease when lowered into the bath in a sieve or perforated ladle.

(ii) Penetration up to ·010 in. can be obtained and the surface is free of scale.

(iii) Cellulose enamel is a protection against the salts, but Cu is not.

(iv) A hood is required to carry away irritating fumes from the bath.

Dynamic Balancing. (See page 29 for full particulars.)

Static Balancing. (See page 29 for full particulars.)

Etching. Parts are immersed in an etching bath to show up surface defects. When etching steel, occlusion of hydrogen may occur particularly with those of low ductility, when penetration is greater. Heat-treatment after etching is essential. This can be done by heating the part from 100° C. to 150° C. for one hour, either in an oven or an oil bath.

Honing. This process applies largely to cylinder bores, and consists of polishing the surface after the final machining operation. The hone incorporates a number of spring-loaded grinding stones, and is arranged to reciprocate at the same time as it rotates. The grade of stone, the nature of the lubricant, and the speed of operation are all important.

Nitriding. (See page 37 for particulars.)

Patenting. A heating process, introduced in the manufacture of steel wire, to encourage crystal growth, prior to drawing.

Pickling. This is done by immersing steel parts in an acid bath in order to clean the surfaces and remove scale or oxide films. With this process there is danger, due to penetration of the acid and resultant weakening of the crystal boundaries, particularly if the part is left a long time in the bath. Subsequent heat-treatment is of no avail, and an inhibitor should, therefore, be introduced into the solution.

Scintilla Hardening. This is a simple method of securing a skin-hardened surface on case-hardening steels, but is not extensively used on aircraft engine parts. The part is heated, sprinkled with scintilla powder, and quenched. The hardening penetrates to a depth of from ·002 to ·003 in.

Sintering. Powdered metals, their oxides or carbides, are subjected to heat at temperatures just below their melting points. Pressure is then applied to make the grains adhere together and produce a strong and, if possible, porous matrix. Bearings have been produced by interposing sintered metal to provide a bond between the lining and the shell.

Stabilizing. This is a form of annealing carried out below the tempering temperature in a controlled atmosphere, and long enough to release internal strains. It improves the impact value and eliminates distortion by assisting uniform growth. Stabilizing often precedes nitriding.

Tricolizing. This consists of the electrical deposition of metal, principally iron, on steel parts. Its application to aero-engines is mainly in

restoring housings and journals that have worn beyond the maximum permissible dimensions. The built-up part is then restored to its correct dimensions by grinding in the ordinary way.

Welding. (See page 21 for full particulars.)

7. HEAT-TREATMENT

(Ferrous)

Annealing. (See page 31 for full particulars.)

Burnt Steel. When a steel is heated to a high temperature, fusion may occur in the outer layers. Decarburization is pronounced, and oxide films may be found in the grain boundaries of the ferrite and pearlite, and cracks are likely to occur. The cracks and brittle structure can only be removed by re-melting the steel.

Cold Short. This is a condition of steel when hammering or rolling, below a dull red heat, will result in fracture or cracking.

Critical Point. (See page 30 for full particulars.)

Equilibrium Value. The variation in change point temperatures on cooling and heating a steel.

Hardening. (See page 31 for full particulars.)

Hot or Red Shortness. This is a condition in certain materials where working at a red heat is liable to induce crack formation.

Normalizing. (See page 31 for full particulars.)

Recalescence Point. The point on the cooling curve of a steel where the carbides are precipitated. This is accompanied by a slight rise of temperature. In wire drawing, the red-hot wire may be seen to increase momentarily in brilliance as it cools through this point.

Refining. (See page 35 for full particulars.)

Solid Solution. This is the result of the absorption of one solid by another, just as water absorbs sugar. In its application to steel, C is absorbed by the ferrite.

Tempering. (See page 31 for full particulars.)

Temper Brittleness. This is sometimes known as Krupp Krankheit. Certain nickel chrome steels, when subjected to slow cooling from their tempering temperatures, show very low impact values on the notched bar test, and are consequently brittle. Small quantities of Mo normally ensure freedom from temper brittleness.

Micro-Structures

Austenite. A solid solution of C in Gamma iron formed at temperatures above the upper critical range and partly maintained below this range by rapid quenching from a high temperature.

Cementite. Carbide of iron, Fe_3C (6.7 per cent C and 93.3 per cent Fe). Cementite is "combined" in Gamma iron but crystallizes out in Alpha iron.

Dendrite. Steel which has a coarse "fir-tree" type of micro-structure. Considerable segregation of carbon occurs during the solidification of the steel in the ingot mould, and is only partly dispersed by subsequent treatment and working.

Ferrite. This is pure iron. It is soft and ductile and has practically no hardening power. Crystals are cubic in shape.

Pearlite. This is a mixture of Cementite and Ferrite and is formed when a steel is cooled normally through the upper critical range temperature.

Martensite. This is a hard, brittle mixture of Carbide of Iron with Alpha iron, and is obtained by rapid quenching of the steel from above the upper critical range temperature.

Sorbite. This is the last stage of transformation of Martensite into

lamillar Pearlite. The stages being Martensite, Troostite, Sorbite, and finally Pearlite.

Troostite. This is the first breakdown product of Martensite. When a steel is reheated (tempered) at a low temperature, the carbide commences to separate in a finely divided state. It can also be formed if quenching is not rapid enough to preserve the Austenite but too rapid to form Pearlite.

Macro-etching. The structure of the material is made visible to the naked eye by treatment with suitable reagents, usually acids in the case of steel and solution of caustic soda in the case of non-ferrous materials, such as Al.

Micro-photograph. This is a photograph of the specially prepared surface of a piece of metal after magnification up to 250 times. The prepared surface is etched with various reagents according to the class of material.

(NON-FERROUS)

Age-hardening. This is hardening of certain aluminium alloys through the breakdown of the solid solution over a period of time at room temperatures. "Precipitation heat-treatment" is artificial age-hardening by subjecting the part to a temperature usually below 200° C.

Modified. A term implying that the Si in Si-Al alloys is minutely dispersed, and the alloy is uniform and free from hard inclusions. This result is obtained by suitably fluxing the molten Al with metallic sodium or sodium fluoride when adding the 50/50 Si-Al compound. The fracture will exhibit brilliant pits if the material is over modified and a coarse fracture if under modified, whilst complete modification will show a silky white fracture.

8. ACCESSORIES

(CARBURETTOR)

Accelerator Pump. This pump injects fuel into the choke tube whenever the throttle is opened, the quantity of fuel being proportional to the amount of throttle movement. There is also a delayed action pump incorporated on some carburettors.

Automatic Boost Control. This mechanism automatically regulates the boost pressure, so that the specified boost cannot be exceeded.

Boost Gauge. An instrument incorporating an aneroid which records the pressure in the induction system above or below that of the atmosphere at sea-level. It should read zero at standard atmospheric pressure, namely, 760 mm. (engine stationary).

Balance Pipe. A pipe or passage incorporated in the carburettor to balance the air pressure between the float chamber and the air intake.

Choke Tube. A restricted and calibrated passage situated between the air intake and the throttle orifice.

Diffuser. A component of a carburettor, usually consisting of a round perforated tube, which assists in atomizing the fuel before it enters the choke tube.

Mixture Control. This is sometimes referred to as altitude control, and consists of a valve by means of which the mixture strength can be varied to accommodate conditions at altitude.

Power Jet. A jet supplementing the normal fuel supply from the main jets which comes into operation at throttle openings about or above 9/10ths power. The jets are normally adjustable cam-operated needle valves.

Reference Jet. This is a jet used for calibrating scale plates on apparatus used for checking standard jets. The reference jet gives the flow in cubic centimetres per minute of pure benzole under constant pressure head of 50 cm. at 60° F. Standard jets must be accurate to within plus/minus 1 per cent up to 200 c.c. flow per minute and plus/minus ½ per cent for 200 c.c. flow per minute and above.

(ELECTRICAL)

Bonding. This is a means of making a complete "Earth" throughout the engine, thus preventing a tendency to electrical leakage, in the form of a spark, between any insulated parts.

Condenser. This comprises a large number of strips of tin foil insulated from each other by sheets of mica and so arranged that all the alternate sheets of foil protrude from one end of the pack and are electrically joined together. The other strips protrude from the other end of the pack and are also joined together. A high potential can by this arrangement be built up. The condenser prevents arcing at the contact-breaker points.

Polar Inductor Magneto. This type of machine has a stationary armature in which the primary circuit is generated and the secondary current induced. The E.M.F. reaches a maximum four times during each revolution of the rotating member (the polar inductor), thus providing four sparks per revolution. It operates at half the speed at which a rotating armature type of magneto does on a similar engine.

Safety Spark Gap. This is required because any undue rise of voltage, resulting from a sparking plug lead becoming detached or any other breakdown in the secondary circuit, would otherwise result in the possibility of damage to the insulation of the armature. The safety gap provides a path for the spark discharge to earth when there is not the usual path across the electrodes of the sparking plugs.

With B.T.-H. magnetos, a brass point from the distributing brush box directed towards the slow speed gear wheel, and a serrated stud screwed into the gear wheel, constitute the poles of the gap. In Watford magnetos, a point from the secondary collector segment to a fixed earth point on the body of the magneto provides the gap.

Screening. The magneto, high-tension leads and sparking plugs are earthed separately from the engine, to prevent wireless interference.

(AIRSCREWS)

Adjustable Pitch. The pitch setting of the blades is effected with the engine at rest.

Variable Pitch. The pitch setting is varied in flight to either coarse or fine pitch.

Constant Speed. A unit controls the movement of the blade settings to maintain a constant engine speed.

Controllable Pitch. This is similar to the constant speed airscrew but in addition the unit incorporates mechanism to vary the spring load on the governor and permit engine revolutions to be maintained by the pilot at any selected speed.

Feathering. The blades automatically revert to full coarse position when the engine comes to rest.

9. ENGINE TESTING

Boost Pressure. See paragraph 5 of Leaflet C2 (A.P. 1208).

Detonation. Also commonly known as "knocking" or "pinking." It is the spontaneous combustion of some portion of the charge, in such a

manner that an extremely sudden and high pressure wave is generated, which on striking the combustion chamber walls causes the "ringing" or "pinking" sound.

Gate Throttle Power. See paragraph 14 of Leaflet C2 (A.P. 1208).

International or Rated Power. See paragraph 6 of Leaflet C2 (A.P. 1208).

International R.P.M. See paragraph 5 of Leaflet C2 (A.P. 1208).

Maximum Permissible Boost Pressure. See paragraph 10 of Leaflet C2 (A.P. 1208).

Pre-ignition. This is the ignition of a charge before it is fired by the sparking plug, and is caused by some overheated part, such as the sparking plug, exhaust valve, or incandescent carbon.

Rated Altitude. See paragraph 8 of Leaflet C2 (A.P. 1208).

Rated Boost Pressure. See paragraph 11 of Leaflet C2 (A.P. 1208).

Sea-level Power. See paragraph 12 of Leaflet C2 (A.P. 1208).

Specific Fuel Consumption. This is fuel consumption in pints b.h.p./hr. under any specific set of conditions, such as weakest maintained, normal rich, etc.

Weakest Mixture for Maintained Power. This represents the weakening of the mixture control on the carburettor to give a drop in h.p. between 0 and ½ per cent, or the weakest mixture with which an engine will run without undue overheating.

10. FUELS

Anti-knock Fuel. A fuel to which benzole, T.E.L., etc., has been added in order to suppress detonation which might otherwise be expected with high compression engines using standard fuel.

Aromatics. These are natural anti-knock constituents of a fuel and include benzene, toluene, and xylene.

Benzole. This consists of benzene plus a trace of toluene. It has the effect of increasing the anti-knock value of a fuel. It has a freezing-point of plus 5° C.

B.Th.U. This stands for British thermal unit, and is the amount of heat required to raise 1 lb. of water at its maximum density, 1° F.

Calorific Value. This is the heat value of a fuel. Aviation petrol has from 18,000 to 18,700 B.Th.U's per lb. Aromatics have from 17,300 to 17,800 B.Th.U.s per lb.

Cracked Spirit. This is a product of the high temperature distillation of crude oil from which petrol is normally distilled. Fuels of good anti-knock quality are obtained by this process.

Ethyl Fluid. This consists of tetra-ethyl lead, 61 per cent by weight; ethylene di-bromide, 36 per cent by weight; pink colouring matter, ·2 per cent. Kerosene and impurities the remainder.

Flashpoint. This is the temperature of an inflammable liquid at which the vapour liberated is inflammable enough to flash if in contact with a naked flame.

Latent Heat. This is the heat required to change the state of a substance without change of temperature.

Octane Number. This is the anti-knock value of a fuel. The fuel is tested on the standard knock-testing engine, and the degree of detonation is measured in relation to a reference fuel, the detonation characteristics of which are known. The reference fuel consists of a mixture of iso-octane (low detonation spirit) and normal heptane (high detonation spirit). The octane number is the percentage by volume of the former in an iso-octane-heptane mixture, which matches the fuel to be tested. In view of

the cost of this reference fuel, sub-standard fuels are used. Fuel to Specification D.T.D.134 had an octane number of 75 to 76. Fuel to Specification D.T.D.224 has a minimum octane number of 77. Fuel to Specification D.T.D.230 has a minimum octane number of 87, with up to 4 c.c. of T.E.L. (not fluid) present. It is tinted pink and 100 octane fuel is tinted green.

Petrol. This is a trade name for a spirit consisting of a mixture of volatile fractions of the paraffin, naphthene, and aromatic series of hydrocarbons.

Specific Gravity. This is the ratio of the weight of any given liquid to the weight of an equal volume of water at 60° F. (water is designated as 1).

Specific Heat. This is the amount of heat in calories required to raise one gramme of the substance 1° C. Gases have specific heats at constant volume and constant pressure respectively.

Tetra-ethyl Lead (T.E.L.). This is an anti-detonant, which is added to a fuel as "Ethyl Fluid," up to 4 c.c. of T.E.L. per gallon of fuel.

11. ENGINE DATA

Torque or Turning Moment. This is known as a "couple," that is a force acting at a given distance from a centre so as to produce a turning or twisting moment.

Thus, if W lb. act at the end of an arm L ft. long.

$$T \text{ (or Torque)} = W \times L \text{ lb.-ft.}$$

Now Work equals the force $\times$ distance moved.

Therefore, the work done by T lb.-ft., when the arm (L) turns through an angle of θ radians

$$= W \times L \times \theta \text{ or } T\theta \text{ ft.-lb.}$$

If N = revolutions per minute the distance travelled by the force
= $2\pi N$ radians and work done during N revolutions
= $2\pi N T$

$$\text{From which B.H.P.} = \frac{2\pi N T}{33{,}000} = \frac{N T}{5{,}253}$$

$$\text{and } T = \frac{\text{B.H.P.}}{N} \times \frac{33{,}000}{2\pi} = \frac{\text{B.H.P.}}{N} \times \frac{5253}{1} \text{ lb.-ft.}$$

Note. A radian (θ) is the angle subtended at the centre by a circular arc of length equal to the radius.

$$\text{Thus } \theta = \frac{180^\circ}{\pi} = 57.295^\circ$$

$$\text{and } \pi\theta = 180^\circ.$$

Horse-power. This is the unit of power, and equals 33,000 ft.-lb. or 33,000 lb. raised 1 ft. in 1 min.

I.H.P. This is indicated horse-power. The horse-power actually developed in the cylinder as calculated from an indicator diagram.

B.H.P. This is brake horse-power, the horse-power actually available at the airscrew.

Mechanical Efficiency. $\dfrac{\text{B.H.P.}}{\text{I.H.P.}}$

It is about 89 per cent for petrol engines. The remaining 11 per cent representing frictional and pumping losses.

Compression Ratio (n). The compression ratio of an engine is obtained from the formula

$$n = \frac{r + R}{r} \text{ or } \frac{R}{r} + 1$$

where R = the volume swept by the piston in the cylinder
r = the combustion space when the piston is at T.D.C.

M.E.P. This is mean effective pressure, and is the average pressure (lb. sq. in.) on a piston during one cycle. This can be ascertained by taking an indicator diagram with a Farnborough indicator, or similar apparatus. The brake mean effective pressure can be calculated from observed brake readings. For a four-stroke engine, the brake M.E.P.

$$= \frac{\text{B.H.P.}}{\text{R.P.M.}} \times \frac{66{,}000}{N \times S \times D}$$

where N = number of cylinders,
S = stroke (ft.),
D = area of the piston (sq. in.).

Volumetric Efficiency. This is the ratio between the volume of mixture taken into the cylinder during the induction stroke and the cylinder capacity at atmospheric pressure with the piston at B.D.C. This may be 80 per cent with a normally aspirated engine, but is increased on raising the induction pressure by supercharging.

Thermal Efficiency. The relation between the heat value of the fuel charge, etc., and the heat converted into actual work. It may be stated thus—

$$\frac{\text{Useful work done}}{\text{Total heat supplied}}$$

This is about 25 per cent for a petrol engine and slightly higher for a compression ignition engine.

Left-hand Engine. This is an engine in which the airscrew shaft rotates in an anti-clockwise direction viewed with the engine between the observer and the airscrew. With a right-hand engine the airscrew shaft rotates clockwise. This definition is applicable to both tractor and pusher engines.

APPENDIX III

CONVERSION FACTORS

1. Pressures
2. Volumes and Capacities
3. Weights
4. Linear and Surface Dimensions
5. Miscellaneous

1. PRESSURES

1 atmosphere	=	A column of H_2O. 33·90 ft. high
	=	A column of Hg. 760·0 mm. high
	=	A column of Hg. 29·92 in. high
	=	14.69 lb. per sq. in.
	=	1·033 Kg. per sq. cm.
	=	1013·2 millibars
1 lb. per sq. in.	=	A column of Hg. 52 mm. high
	=	A column of Hg. 2 in. high (approx.)
	=	A column of H_2O 2·31 ft. high
	=	0·07 kg. per sq. cm.
½ lb. per sq. in.	=	A column of Hg 0·255 of an inch high
1 in. head of Hg.	=	0·0344 Kg. per sq. cm.
	=	A column of H_2O 1·135 ft. high
	=	0·49 lb. per sq. in.
1 mm. head of Hg.	=	A column of Hg. 0·039 of an inch high
	=	0·019 lb. per sq. in.
12 in. head of H_2O	=	0·433 lb. per sq. in.
	=	A column of Hg. 0·882 of an inch high
12 in. head of fuel	=	S.G. × 0·433 lb. per sq. in.
	=	A column of Hg. S.G. × 0·882 in. high
10 in. head of fuel (S.G. 0·76)	=	·274 lb. per sq. in.
12 ft. head of fuel (S.G. 0·76)	=	3·95 lb. per sq. in.
27½ in. head of H_2O	=	1 lb. per sq. in.
1 ton per sq. in.	=	1·575 kg. per sq. mm.
1 lb. per sq. in.	=	0·0703 kg. per sq. cm.
1 kg. per sq. mm.	=	1422·4 lb. per sq. in.
1 kg. per sq. cm.	=	14·224 lb. per sq. in.
Exhaust back pressure correction		Add 1½ per cent of the observed b.h.p. for each lb. per sq. in. of pressure recorded in the manifold
1 per cent back pressure	=	A column of H_2O 18 in. high (approx.)
1 millibar	=	1000 dynes per sq. cm.

2. VOLUMES AND CAPACITIES

1 cu. cm.	=	0·061 cu. in.
	=	0·0018 pt.
1 cu. in.	=	16·387 cu. cm.
	=	0·029 pt.
	=	0·016 litre
	=	0·0036 gal.
1 cu. ft. H_2O	=	28·375 litres or kg.
	=	6¼ gals. (approx.)

1 pint . . .	=	0·125 gal.
	=	0·568 litres
	=	568·25 cu. cm.
	=	34·66 cu. in.
1 litre . . .	=	0·220 gal.
	=	1000 cu. cm.
	=	1·760 pt.
	=	61·0 cu. in.
1 millilitre . .	=	1 cu. cm.
1 gallon (Imperial)	=	4·546 litres or kg.
	=	10·0 lb. H_2O (fresh)
	=	1·205 U.S. gal.
	=	277·3 cu. in.
1 cu. ft. H_2O per sec.	=	373·8 gal. per min.

3. WEIGHTS

1 cu. ft. of H_2O .	=	62·42 lb.
	=	1000 oz. (approx.)
1 gal. of H_2O at 62° F.	=	10 lb.
1 lb. of liquid. .	=	0·8 ÷ S.G. pt.
1 pt. of liquid .	=	1·25 × S.G. lb.
1 litre H_2O . .	=	61·0 cu. in.
	=	2·2 lb.
	=	1 kg.
1 oz.	=	28·35 grammes
1 lb. (Av.) . .	=	0·4536 kg.
1 gramme . .	=	0·03527 oz.
	=	0·565 drams
	=	1 cu. cm. of H_2O
1 dram (Av.) . .	=	1·773 grammes
1 kg. . . .	=	2·205 lb.
1 lb. H_2O . .	=	27·69 cu. in.
	=	0·4536 litres or kg.

4. LINEAR AND SURFACE DIMENSIONS

1 in.	=	25·40 mm.
$\frac{1}{1000}$ in. . . .	=	0·0254 mm.
	=	0·001 in.
1 cm.	=	0·3937 in.
1 mm. . . .	=	39·37 thousandths of an inch
	=	0·0394 in.
1 sq. in. . . .	=	6·4514 sq. cm.
1 sq. cm. . .	=	0·155 sq. in.
$\frac{1}{64}$ in. . . .	=	0·015625 in.
	=	0·397 mm.

$\frac{1}{32}$ in. . . .	= 0·03125 in. = 0·794 mm.
$\frac{1}{16}$ in. . . .	= 0·0625 in. = 1·587 mm.

5. MISCELLANEOUS

(a) Power

1 British horse power . .	= 33,000 ft. lb. min. = 746 watts (amperes × volts) = 1·0139 × French horse-power = 42·4 B.Th.U./min.
1 French h.p. . . .	= 0·986 × British h.p. = 75 kilogrammetres/sec.
1 kilogrammetre[1] . . .	= 7·233 ft. lb.
1 ft. lb.	= 0·1382 kilogrammetre
1 British thermal unit (B.Th.U.)	= 778 ft. lb.

(b) Speed

1 mile per hour . . .	= 0·445 metres per sec. = 1·467 ft. per sec. = 88 ft. per min.
60 miles per hour . . .	= 88 ft. per sec.
1 knot (nautical mile) . .	= 1·152 statute miles per hour
1 knot	= 1853 metres
1 mile	= 1·609 kilometres
1 kilometre	= 0·621 miles

(c) Temperatures

Degrees Fahrenheit . .	= (Degrees Centigrade × $\frac{9}{5}$) + 32
Degrees Centigrade . .	= (Degrees Fahrenheit − 32) × $\frac{5}{9}$
Freezing point H_2O . .	= 0° C. = 32° F.
Boiling point H_2O . .	= 100° C. at 14·69 lb. sq. in. = 212° F. at 14·69 lb. sq. in. = 92·5° C. at 10,000 ft.
Absolute zero . . .	= − 273° C = − 459·4° F.

(d) General

1 millivolt	= $\frac{1}{1000}$ volt
a milliampere	= $\frac{1}{1000}$ ampere
1 Radian	= 57·3 degrees.

[1] Work done by 1 kg. exerted through a distance of 1 metre.

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